The Gullies of the Canterbury Bight:

Rakaia to the Rangitata

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Abstract

This thesis is an investigation into some erosional gully features of the landscape along the coastal margin of the Canterbury Bight, east coast of the South Island, New Zealand. These gullies range in size from only a few meters up to 6km in length and are a significant aspect of the landscape between the Rakaia and Rangitata Rivers.

An examination of vertical aerial photographs revealed numbers in the order of 300 gullies, although a substantial number of these can be identified as aspects of coastal cliff retreat. A number of gullies have been surveyed and ground truthed using standard surveying techniques in order to make out any distinguishing characteristics. Oblique aerial photographs were taken so as to enhance the vertical aerial photographic interpretation.

Cliff retreat along this coastline is averaged at 0.5m/yr and has been found to have considerable impact on the gullies as they are relict features and consequently, their development is not in keeping with the rate of cliff retreat. It has been found that there are at least three groupings of the gullies in relation to their size, those being *small*, *intermediate* and *large*.

The formation of the larger gullies has been initially attributed to subsurface processes, producing surface irregularities in which continued erosion can concentrate. It has also been estimated that the gullies were initiated between the period of 150 to 600 years BP, but that it is most likely that all gullies were not formed at the same time. The most probable explanation found that the three different gully sizes identified can be attributed to having developed in three different time periods.

Acknowledgments

My sincerest thanks go to my family. My parents for their support both financial and otherwise I am forever grateful. Without the support of my family, I would never have come this far. Thank you.

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If there is anyone that I have missed out here, I apologise. All help along the way was appreciated.

Here reaches an end of an era (a long one at that!).

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Chapter One

Introduction

1.1 Introduction

This study concerns the coastal cliffs of the South Canterbury Bight (Figure 1.1) which are home to a number of incised gullies of up to 6km in length. These gullies run roughly perpendicular to the present coastline along the Canterbury Plains between the Rakaia and the Rangitata Rivers. Banks Peninsula divides the Plains into northern and southern sections. However, the gullies are found only in the southern section, south of the Rakaia River. These gullies were described by Schumm and Phillips (1986) as having "irregular margins, stubby tributaries and flat-appearing but actually irregular floors". A large number of the gullies are now dry and relict features of the landscape. Some of the gullies are accordant at the coast; others are discordant or 'hanging'. The physical appearance of the gullies is important as it helps determine their most likely origin in accordance with the models on gully development found in the wider body of international literature. The gullies described in this research are found extensively between the Rakaia and Rangitata Rivers, although, they do occur to a lesser degree south of the Rangitata River.

This thesis examines the gullies of the South Canterbury Bight and their temporal development in relation to the conditions under which they were formed. The origin of these gullies is problematic in that there are few with an identifiable contemporary stream or river enclosed in them, yet they are substantial features of the landscape. Schumm and Phillips (1986) attribute the initiation of the gullies on the central Canterbury Coast to overland flow from swampland, which until the 1870's dominated this region. Schumm and Phillips (1986) went on to suggest that after initial formation, sub-surface sapping was responsible for their continued development. The problem with this explanation is that the region of swamp they discussed, only extended a short distance between the Hinds and Ashburton Rivers, so this theory is not applicable outside this boundary, yet the gullies can be found well outside these limits for up to 20km either side. The extent of the swamp in this area is discussed more fully in Chapter Two.

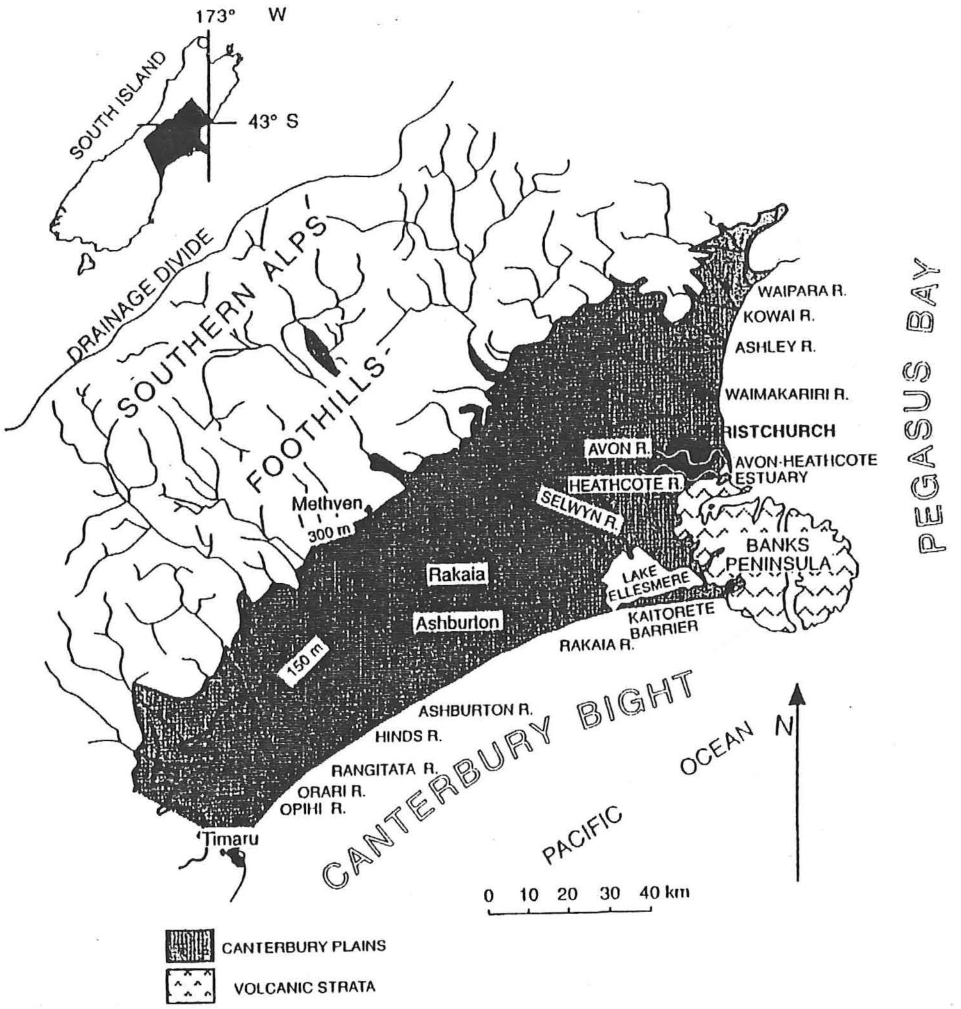

Figure 1.1: The Canterbury Bight

(From Leckie, 1994 p.1241)

Although, to the author's knowledge, the Schumm and Phillips paper is the only one dealing specifically with these landforms. These gullies have been of considerable interest to different parties since the 1860's. Some were first used as drainage outlets from the swampland in the area. Currently the Department of Conservation (D.O.C) are interested in conserving these landforms. However, some landowners are actively opposed to this idea which has consequently been the topic of some controversy.

This interesting debate lies beyond the scope of the present research, which is a scientific investigation into some unusual and interesting landforms that appear to be 'fossil' in the present landscape. Between the 1860's and present these gullies have been used for a variety of purposes including irrigation and for dumping rubbish and carcasses. This goes some way to explain the deficit of literature pertaining to these gullies as they have only recently been assigned any importance.

At some point, probably during the late 1940's, the gullies started to be referred to as 'dongas', a Zulu derivative meaning 'a wall', which, in Southern Africa is used to denote gullies, in much the same way as arroyo has a similar meaning in America and wadi in Northern Africa. It is thought that the term donga made its way here via an ex army member who had been located at some point in Southern Africa and who upon his return obtained employment in the South Canterbury Catchment Board (SCCB) (*pers. comm* T.I.Goodwin). Whether the gullies of the Canterbury Bight are similar to South African dongas will be examined in a later chapter.

1.2 The Study Area

The Canterbury Plains are comprised of unconsolidated outwash sands and gravels of at least 900m in thickness and are the result of fluvial deposition from the main river systems, those being the Rangitata, Ashburton, Rakaia and Waimakariri with the headwaters extending from the Southern Alps (Leckie 1994, Fitzharris et al 1982). The Canterbury Plains therefore are alluvial fans, the result of outwash debris from the major river systems and glaciers that at previous times dominated the headwaters of these systems. The fan surfaces in which the gullies are formed are comprised of unweathered sands and gravels and often have a capping of loess. These points are discussed in Chapter Two.

The coastal cliffs range in height from approximately 6m to 25m and are composed of unconsolidated gravel. The source of this material has been brought down through fluvial action by the major river systems from the Southern Alps. Currently these cliffs are recorded as eroding at an average rate of 1 m/yr with a maximum rate of 1.53 m/yr recorded (Flatman, 1997; Leckie, 1994). Since the coast is eroding so rapidly, and has been doing so for thousands of years, the possibility is raised that this has greatly impacted upon the physical appearance of the gullies. According to Hemmingsen (1997) the coast of the Canterbury Bight would have been up to 48.5km further east during lowstand sea level periods. This raises the possibility that the erosion occurring along the coastline has modified the gullies, as they may have extended much further to the east in the past at a time of lower sea level.

The impact of both coastal and gully erosion within the study area is significant for current land use and conservation issues, particularly in regards to the management of the land resource (Burkard and Kostaschuk, 1995; Seginer, 1966). In such regions, strategies to limit expansion are important as high rates of gully erosion can lead to severe loss of serviceable land. It is therefore important to gain some knowledge and understanding of both the processes involved in the initiation and the growth of gullies.

1.3 The Gullies

The most extensive gullying seems to be associated with the Hinds and Ashburton Rivers and the Wakanui Creek area where some of the gullies are 6km in length. However, most gullies extend less than 1km from the coastline, and many small, steep sided gullies reach only 10's of meters from the coastline. Figure 1.1 gives an indication of the location of the gullies between the Rakaia and Rangitata Rivers. The appearance of the gullies varies considerably and to describe the gullies in a very broad sense, it could be concluded that most are dry and have no apparent present water source, unless artificial. As can be seen in Plate 1.1, some have relatively steep sides and headcuts.

These gullies are poorly vegetated (if at all), probably due to the nature of their steep, unconsolidated sides, a product of the coastal cliffs along which they are found. These small gullies are often used as outlets for irrigation as can be seen in Plate 1.2. This is important in that the concentration of water into these outlets would seem to have an erosive force resulting in the back cutting of the gully head. This can be seen in Plate 1.2 where it has resulted in the partial collapse of a boundary fence.

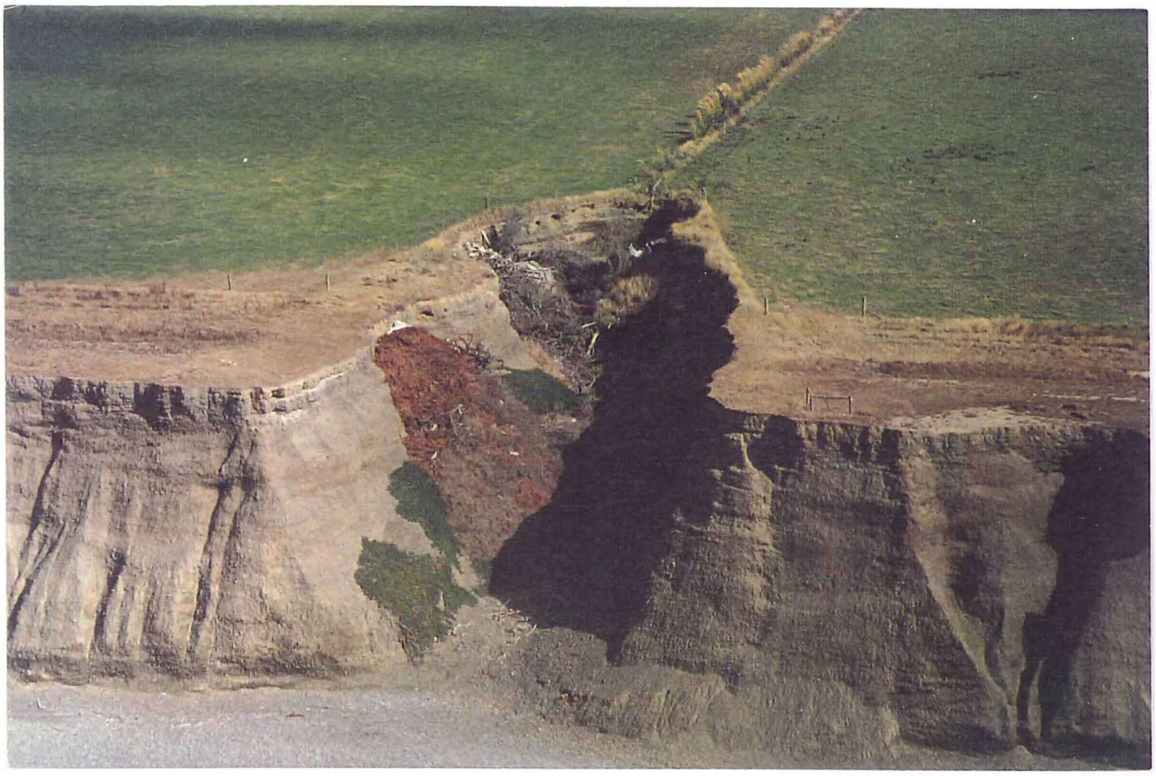

Plate 1.1: An example of a steep-sided gully

In contrast other gullies tend to be substantially larger (Plate 1.3) with more gently sloping sides and bottom channel. These gullies tend to have an established vegetation cover except in places (as in the break in slope) where the angle is too great to sustain growth. These larger gullies are inclined to have a more complex structure than the smaller ones in regards to branching. The larger, flat-bottomed gullies tend to possess a number of tributaries extending from the main channel.

Plate 1.2: An example of a small gully being used as an irrigation outlet

Plate 1.3: An example of a larger gully with a flat bottom channel

The small, steep gullies are typically V-shaped in cross-section while the larger, more established gullies are characteristically more complex in form and tend to have relatively flat floors. There are also a number of gullies that fit in an intermediate category (Plate 1.4) that although vegetated, still have relatively steep sides and are more V-shaped in regards to the cross profile.

Plate 1.4: An example of an 'intermediate' gully

1.4 Research Aims

The aims of this research are to examine the character and development of the gullies found on the coastal cliffs of the South Canterbury Bight in relation to the conditions of their formation. A descriptive analysis of the Canterbury Plains, their formation and history is the first aim of this thesis to gain an understanding of why the gullies have formed in the particular areas in which they are found. Since there have been no extensive studies on these landforms, a major part of this thesis is to investigate and describe the extent and forms of the gullies and their location. There are two main aims to this thesis:

1. Investigate and describe the extent and location of the gullies
2. Examine their form and development in regards to their mode of formation

1.5 Thesis Outline

This thesis is predominantly a descriptive analysis of the gullies found on the coastal cliffs of the South Canterbury Bight. Therefore, an examination of the area in which they are found is crucial to this work. Chapter Two addresses this by examining the historical development of the Canterbury Plains particularly in relation to the geomorphology and hydrology of the area. Previous climate and land use will be considered as important indicators of development of the area. The influence of colonial farming practices and past land use is also explored as an antecedent to possible gully development.

Chapter Three presents a literature review to place this research within the larger established literature on 'gullies'. This chapter introduces the different types of gullies, their classification and mode of formation. It focuses on the specific characteristics of each type of gully within the classification system used throughout the wider international literature pertaining to this topic.

A more detailed description of specific field locations and the methodology used in this study is discussed in Chapter Four. In this chapter the methodology is discussed, initially in relation to the broader scale, then focussing on particular field study sites. The three gully classification types as identified in Chapter Three, which are used in this research, are present here. Initial results are also presented in this chapter. The results from Chapter Four are presented and discussed in detail in the next chapter.

Chapter Five is the discussion chapter. It ties the information from all the other chapters together in a discussion, making inferences about the time and mode of formation of the gullies. The final chapter, Chapter Six, outlines the conclusions of this research. This chapter also recalls the objectives of the study and addresses areas for future research.

Chapter Two

The Study Area: Physical Setting

2.1 The study area: physical background

This chapter examines the historical and geographical context of the Canterbury Bight gullies. Important elements of this context are the structure of the Canterbury Plains and the way in which they were formed, along with aspects of past climate regimes and vegetation cover. Equally important is the presence and movement of water both surface and subsurface and knowledge of the material through which it is flowing. These factors are examined in order to create an understanding of the processes at work in the formation of these 'gullies'.

2.2 Location

2.2.1 The Canterbury Plains

The Canterbury Plains, an extensive area of outwash gravels, are the largest area of flat land in New Zealand (Soons, 1968). Approximately 70km wide and 180km in length (Fitzharris *et al.*, 1982) the plains are bounded in the west by the Southern Alps and in the east by the Pacific Ocean (Figure 2.1). The Canterbury Plains are divided by Banks Peninsula and the large braided rivers (Rangitata, Rakaia and the Waimakariri) that run from the Main Divide across the plains to the sea. It was these rivers that during successive glaciations, supplied the glaciofluvial and fluvial sediments that makes up the plains (Fitzharris *et al.*, 1982; Soons, 1968).

2.2.2 Rakaia to the Rangitata

The gullies pertaining to this study occur along the east coast of the Canterbury Plains between the Rakaia River and south of Timaru, a distance of approximately 100km, although the majority are found on the 60km coastal strip between the Rakaia and the Rangitata Rivers (Figure 2.1). It is within this last mentioned area that this thesis will focus. More detailed information about specific field sites will be presented in Chapter Four when dealing with methodology and results of field site investigations.

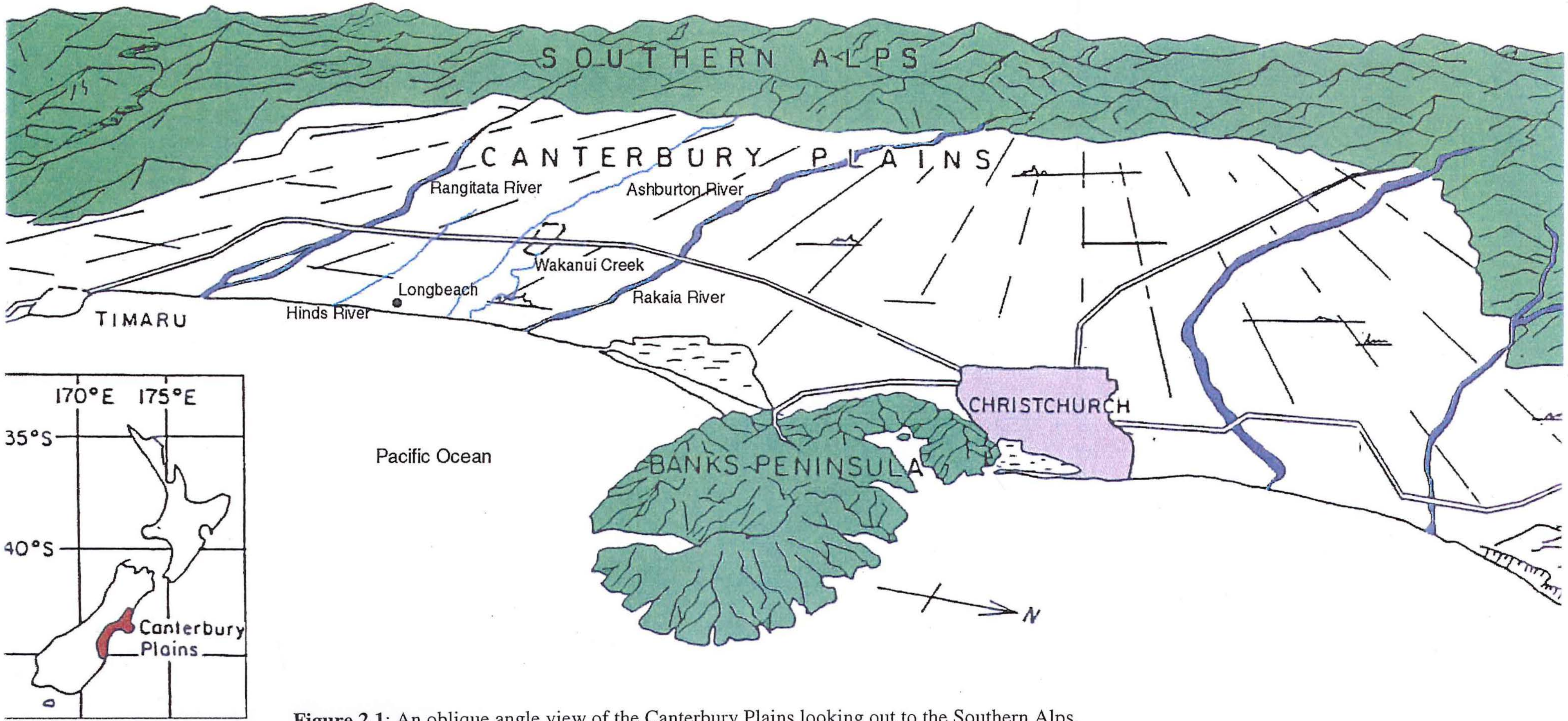

Figure 2.1: An oblique angle view of the Canterbury Plains looking out to the Southern Alps.
(After McKendry et. al; 1987, p62)

2.3 Formation of the Canterbury Plains

The Southern Alps began their uplift during the Kaikoura Orogeny, activity that continues unabated today. This period of mountain building had its origin during the Quaternary phase some 5-2 million years BP (*before present, where present is taken as 1950*). As the Southern Alps were rising, so too were world sea levels (Soons, 1968) meaning that all but the highest points of the Alps were submerged under water (Stevens, 1988). About 2.4 million years BP the onset of the Pleistocene saw repeated global climatic changes occur. The Pleistocene was characterised by a number of intense cold periods (*glacials*) interchanging with a number of intermediary warmer periods (*interglacials)*. It was during these periods that glaciofluvial and fluvial outwash sediment that make up the fans of the Canterbury Plains were laid down.

Soons (1968) associated glacial advances with greater fluvial activity on the Plains. During the 'cold' glacials a degeneration of vegetation resulted in increases in effective mechanical weathering and amounts of waste material. The glaciers themselves were also increasing the load supplied to the rivers due to the erosive action of the glaciers moving down-valley. This resulted in massive outpourings of gravel from the major rivers being deposited in sheets constructing convex fans. Intermittently laid down with this gravel material were layers of loess (fine wind blown sediment) produced due to a reduced vegetation cover.

During the warmer interglacial periods, the glaciers retreated, many disappearing altogether. During these times, the rivers were much smaller and carried a lesser load as the re-establishment of vegetation reduced mechanical weathering. Rivers during this time were not laying down sediment but rather eroding it as they incised into their fans.

With each new phase of aggradation, another alluvial fan was laid down which overlapped the previous one (Figure 2.2), thus successive fans were built up with age increasing from east to west (Soons, 1968). It is estimated that this alluvial sediment ranges in depth from 500-700m that is now capped with a layer of loess. These alluvial fans extend eastwards more than 50km off the present coast (Kirk *et al.*, 1977; Kirk, 1980) onto the continental shelf which extends 90km to the east (Herzer, 1981).

The coastline of the Canterbury Bight is cliffed, with heights of these cliffs varying considerably from 9-25m. The variation in cliff height is related to the way in which the fans were laid down with the higher cliffs being associated with the larger catchments and the more active rivers of the time (Rangitata, Rakaia and Ashburton).

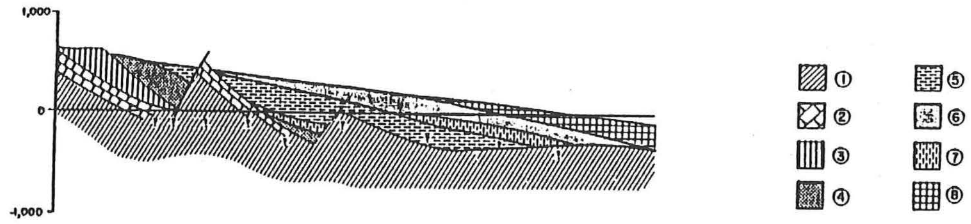

Figure 2.2: Probable structure of the Canterbury Plains depicting different fan layers (from Fitzharris *et al.*, 1992 p.410).

1 Greywacke basement

2 Cretaceous and Tertiary rocks

3-6 Glacial deposits of successive ages

7 Interglacial deposits

8 Postglacial deposits.

Soons (1968) divides the rivers of the Canterbury Plains into two categories. There are those that are 'long rivers' whose source is amongst the mountains of the Main Divide. These include the Rangitata, Rakaia and the Waimakariri and will be referred to as 'Main Divide' rivers. Other rivers, such as the Ashburton, are referred to as 'lowland' rivers, are sourced from the foothills adjacent to the Canterbury Plains ('foothill rivers'). At the time of Plain formation, the Ashburton River was much more active than it is today and played a major role in depositing alluvial sediment (Kelk, 1974; Speight, 1950). Fitzharris *et al.* (1982) recognise another group of rivers of which the Hinds, Ashley and Selwyn are part. These rivers are classified as 'small' rivers, which occupy the interfan depressions and are considered to be partly ephemeral, although under the classification put forward by Soons these are seen as 'foothill' rivers. The rivers that are of interest in the study area are the Rakaia, Ashburton, Hinds and Rangitata and also Wakanui Creek (refer to Figure 2.1).

The 'Main Divide' and 'foothill' rivers tend to respond differently, not generally flooding together. The Main Divide rivers flood in northwesterly rain events following high amounts of precipitation on the West Coast. The east coast is sheltered from this weather system due to orographic effects of the Southern Alps. Other times when the Main Divide rivers flood are during periods of snow melt on the Southern Alps, hence they are seasonal in their flooding regimes. The foothill rivers flood under different circumstances. These rivers rise in periods of heavy rain on the eastern side of the island, brought about by southerly or northeasterly events. The catchments for the foothill rivers are significantly smaller than the Main Divide rivers, which consequently have much larger discharges and higher sediment loads.

The sediment of the Plains consists of layers of gravel and sand of Greywacke origins and wind blown loess layers of silt and clay. Large pore spaces between sediment of gravel size allows for storage of large quantities of water travelling through aquifer systems out to the Pacific Ocean through the Plains from the Southern Alps. Soons (1968) describes how during periods of interglacials, the major rivers incised into the outwash deposits. With each successive glacial event, these are subsequently infilled. The location of the rivers varied with each interglacial, resulting in a succession of valley fills. Scott (1980) recognised that these younger, infilled sediments from more recent events make up the aquifer systems. He also found that transmissivity generally decreases with depth and distance inland away from the coast as the deposits get older. The development of cliffs and subsequent burial between glacial events results in abrupt changes in the aquifer properties in relation to previous cliff positions.

Water moving through the Plains is confined to layers of high transmissivity, unable to penetrate layers with low permeability. Plates 2.1 and 2.2 clearly illustrate the layering of sediment that makes up the Plains. Layers of large gravel sized sediment, interrupted by layers of medium or fine sediment are easily distinguishable from one another. A poorly sorted medium sized gravel layer set with coarse silt (b) can be seen to be eroding between two layers of large gravel sized material (a & c) in Plate 2.2. This is more evident in the lower left corner of Plate 2.2 where a large hole has formed with the removal of medium to fine sediment beneath a more stable, hardpan layer of large gravel sized sediment (d) indicating that some layers are more easily eroded than others. Speight (1950, p10) refers to a 'sub-surface layer of impervious material' in relation to

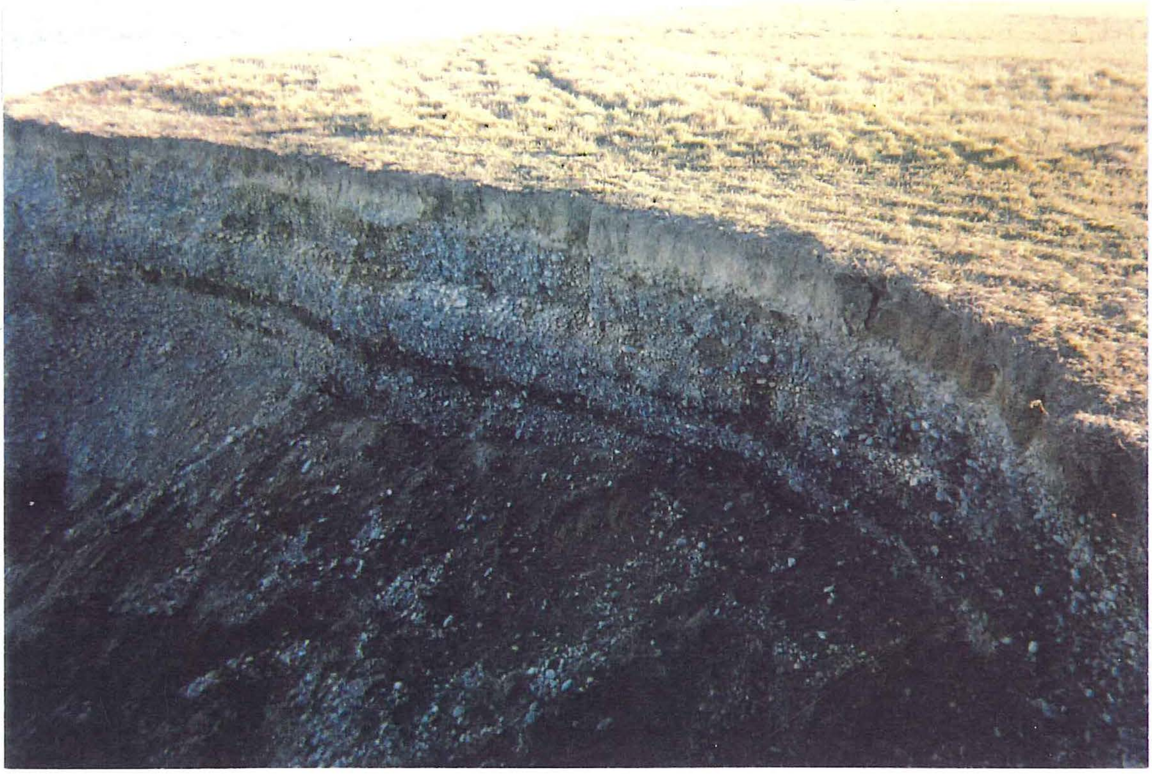

Plate 2.1: Layering of sediment within the coastal cliffs of the Canterbury Bight.

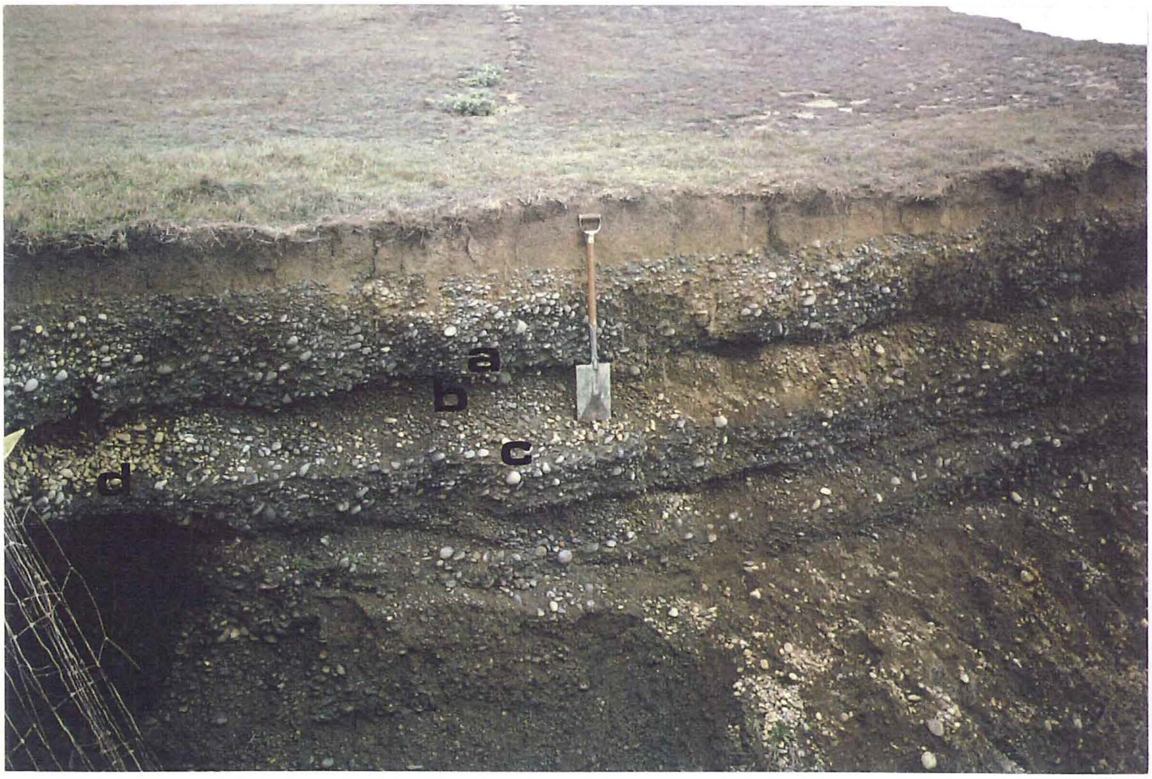

Plate 2.2: Erosion of fine sediment between more stable layers of coarse material.

layers of wet and dry material within the sediment structure in proximity of the Canterbury coast. This factor of a more stable, hardpan layer will be returned to in Chapter Three when dealing with modes of gully formation.

2.4 Coastal Cliffs

The coastline of the Canterbury Bight is in long term erosion with average rates of erosion being in the order of 1-1.5m/yr (Kirk, 1967; Kirk, 1969; Kirk *et al.*, 1977; Flatman, 1997) although this figure is an estimated average and variations do occur. Kelk (1974) measured amounts of erosion of 1.53m over a nine-month study period and attributed this to unseasonally wet weather. This nine-month period didn't include the characteristically high erosion period during winter months so actual amounts for the year could have been substantially greater.

Cliff retreat along the Bight is due to a number of processes, both subaerial and marine. Subaerial processes are those occurring above the land surface as opposed to marine processes, which are connected with action from the sea. Pieters (1996) accredits surface and subsurface water transport as being the main element in coastal cliff retreat while Kelk (1974) identifies slumping along weak fractures due to gravitational forces as the major component. Both authors recognise that marine action is responsible for removal of the eroded sediment that forms talus slopes accumulated at the cliff base which can be seen in Plate 2.3.

The shoreline of the Canterbury Bight is a geologically recent one resulting from variations in sea level (Kirk, 1969). Wilson (1985) puts the coastline during each glacial maximum ca 90km further offshore than its present level due to a sealevel approximately 120m lower than its current level. This is 20km more than Browne and Thrasher's (1996) estimate of 70km. Kirk (1969) suggests a maximum Pleistocene lowering of sea level to 100m below its present position, with the shoreline extending 30 miles (48km) is a generally accepted figure.

Kirk (1967,1969) and Suggate (1958) date the post-glacial highstand to approximately 5,000 years ago. Since this time, sea level has remained relatively stable at or near its present level. Flatman (1997), by extending the gradient of the plains until it intersects the present sea level, estimates cliff retreat of 2.5-5km during this period (5,000yrs). He pointed out this was consistent with an observed present rate of erosion of 0.5-1 m/yr^{-1}. This is also in keeping with Speight's (1930) estimate that a strip at least two miles (approximately 3.2km) in width has been eroded from the fan fringe. Rates of erosion of this magnitude could be expected to continue as Kirk (1969) states that a stable equilibrium might never occur along this stretch of coastline.

Plate 2.3: An example of talus slopes accumulated at the cliff base.

Erosion of this extent could obviously have quite a large impact on the gullies found along the cliffs of the Canterbury Bight as cliff retreat would erode the mouths of the gullies. Speight (1930) describes the gullies as entering the sea discordantly because the development of the gullies could not keep up with the rapid advance of cliff erosion. However, this is not true for all gullies so a range of ages and modes of formation is possible. This aspect will be examined in Chapter Four and discussed in Chapter Five.

2.5 **Climate**

2.5.1 Past Climate

McGlone (1988) extensively examined the previous climates of the South Island so only a brief timeline will be presented here. This outline will provide an indication of times when there may have been an increased amount of water present, enough to initiate the formation of the gullies.

Glacial Maximum: 22,000 to 14,000 B.P.

- Little direct evidence for precipitation changes during this period.
- Broad pattern varied considerably in response to local conditions. Exposed areas tend to have less vegetation.

The Late Glacial: 14,000 to 10,000 B.P.

- Precipitation probably increased from 14,000 B.P. but stabilised between 12,000 and 9500 B.P.
- Rainfall and temperatures rose sharply just before 14,000 B.P. having slowly risen since 16 to 17,000 B.P.
- During 12,000 to 9500 B.P. precipitation was lower than it is now.

The Holocene: 10,000 B.P. to the present

Early Holocene: 9500 to 7500 B.P.

- A drier climate than at present is indicated.
- Lower effective precipitation (an estimated 30% depression).
- Weakened westerly and southerly wind flow over New Zealand. A greater occurrence of northerly, anticyclonic systems.

Late Holocene: 7500 B.P. to present.

- The eastern South Island becomes wetter.
- Cooler, wetter and windier conditions in the east and cooler, more variable climates in the west.
- Intensification of both southerly and westerly wind flows probably began at ca 7000 B.P.

2.5.2 Present Climate

The Canterbury Bight is oriented in a NE-SW direction with the open coastline facing the SE (Kirk, 1967). This, along with the positioning of the Southern Alps is a controlling factor of the weather in this region. McGlone (1983) describes the east coast of the South Island as having the lowest rainfall in New Zealand, the highest frequency of drought and a severe winter climate. Kelly (1948) analysed average monthly rainfall over a 25 year period (Table 2.1) which showed that rainfall was relatively constant year-round with a relatively low annual total. Kelk (1974) gives annual precipitation averages in a relative order of 20-30 inches (50-80cm) on the Plains, decreasing slightly to the coast. Tomlinson (1992) shows the distribution of average annual rainfall for New Zealand depicting the effect the Southern Alps have on rainfall in the Canterbury region (Figure 2.3). Speight (1930) hypothesised that the formation of the gullies was initiated in a period when the climate was much wetter than this some 8-10,000 years ago. He gave no evidence to prove the existence of this wetter period and according to McGlone (1988) climates at this time were actually drier than now.

Table 2.1: *Average Monthly Rainfall (Inches) 25-26 Year Period* (from Kelly, 1948, p12)

January	2.76	July	2.58
February	2.12	August	2.09
March	1.72	September	2.45
April	2.26	October	2.33
May	2.39	November	2.33
June	2.36	December	2.71
Total	28.10 (714mm)		

Most of the East Coast's rainfall is associated with south to southwest airflow where cold, moist air has travelled from the Antarctic and upon meeting a warm land mass releases moisture. Orographic effects of the Southern Alps result in high levels of variability between the western and eastern sides of the South Island. Jobberns (1957) talks of the "violence" of the northwest gales associated with this weather system. The dry nor' wester (or fohn wind) is a familiar part of life on the Canterbury Plains normally associated with high precipitation on the West Coast but little or no precipitation on the Plains.

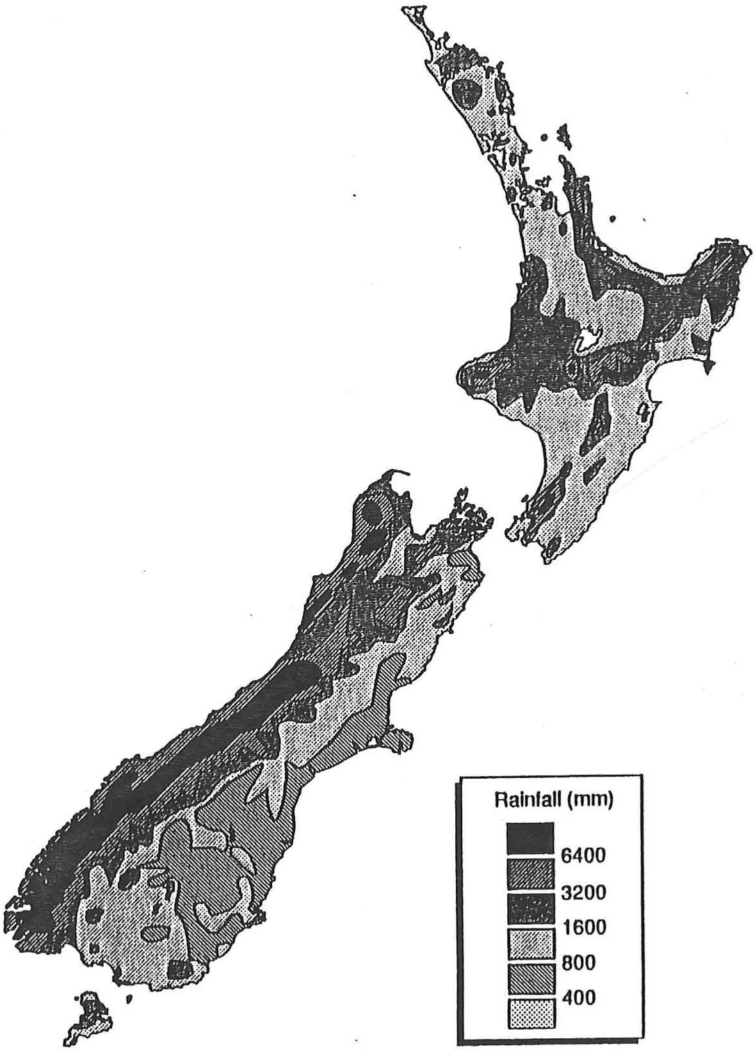

Figure 2.3: Rainfall distribution over New Zealand (From Tomlinson, 1992 p.66).

2.6 Vegetation

2.6.1 Pre European

Before 14,000 years BP, shrub and grasslands dominated most of New Zealand. However, after the last glaciation forest quickly grew back and by 12,000 years BP most areas were forested, except the drier east coast where tussock and shrubland still prevailed (McGlone, 1988). During this period as vegetation cover increased, it may be assumed that a decrease in erosional activity also occurred. Between the period of 10,500 to 9,500 years BP, a rapid change in vegetation cover in the South Island occurred and areas that had previously held out from being forested quickly succumbed (Stevens, 1988). It was during this time that the glaciers were at their smallest and sea level was only 30m below its present level. By 6,000 to 5,000 years BP sea level had reached its present level and the climate had begun to cool. By now, most of the country was covered extensively by forest until ca 2,500-1,500 years BP when forest fires destroyed extensive amounts of forest (McGlone, 1988). Since Polynesian settlement was thought to have occurred between 1,200-1,000 years BP, these fires must have been from natural origins.

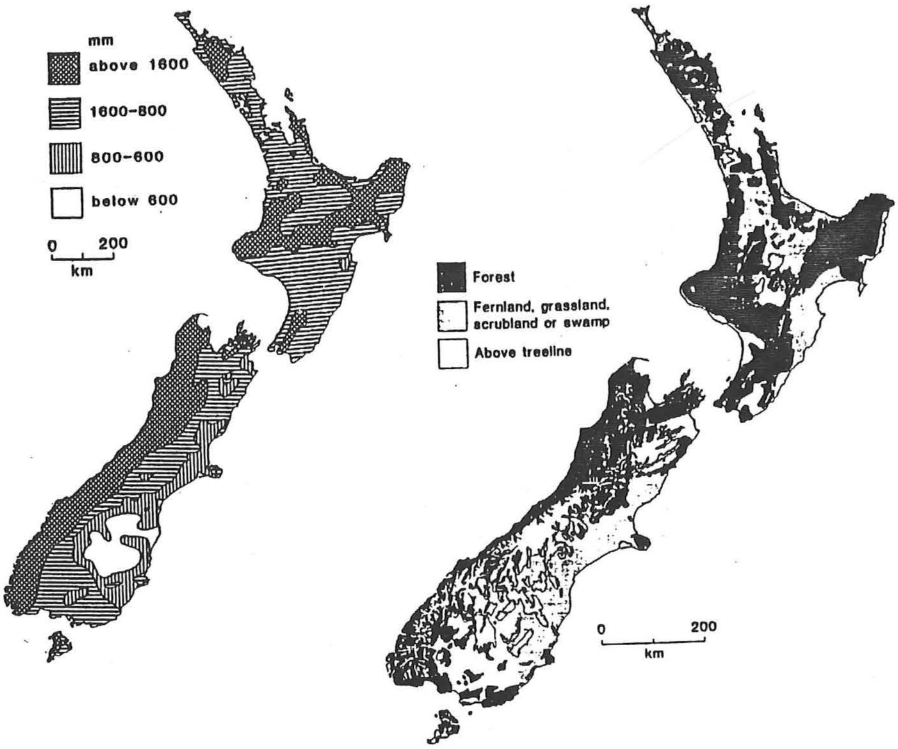

Figure 2.4: Relationship between rainfall and vegetation cover in New Zealand (from McGlone, 1983 p. 12).

The Canterbury Plains recently underwent a change in vegetation cover from forest to tussock coverage. This forest clearance has been attributed to destruction by fire within the last 1,000 years (McGlone, 1983), undoubtedly within the period of Polynesian settlement. Carbon dating has put the destruction of the East Coast forest between 500 and 600 years ago. A debate over whether this vegetation change was due to climatic variations or Polynesian influence fell heavily in favour of the latter (McGlone, 1983). The dry, harsh environment of the eastern South Island may have assisted in keeping the native forest from regenerating in this area. Destruction of forest cover often results in soil instability and increased amounts of erosion. McGlone (1983) found a distinct relationship between rainfall and vegetation cover (Figure 2.4). Figure 2.4 depicts a correlation between low annual rainfall and a lack of forest coverage, clearly showing a lack of substantial coverage in the lower plains of the South Island.

2.6.2 European Settlement

Kelly (1948) describes how early European settlers at Longbeach (refer to Figure 2.1) frequently uncovered large logs while ploughing, making cultivation of the land more difficult. He made no mention as to whether these uncovered logs were charred or not but does comment that no trees were growing on the property when the settlers first arrived.

Figure 2.5 reveals the extent of swampland that dominated the area from the Ashburton River to south of the Hinds River during early European times. Much of this area at the time fell within the boundaries of the Longbeach estate, which was to be taken up by John Grigg in 1864. It is significant that he reported the Hinds River had no outlet to the sea but spread its load into the swamp as can be seen in Figure 2.5. Kelly (1948) reported that subsurface water around the Longbeach area found its passage to the sea blocked by this swamp, hence water would rise to the surface under great pressure as springs. This resulted in variable areas of dry and wet land, 'a reflection of an extremely complex configuration' (Kelly, 1948 p5). This meant that a large reservoir of near-surface water existed in this area of Canterbury around the latter part of last century. One of the first things John Grigg did was to extend the Hinds to the sea via "a convenient coastal gully somewhat larger than the others and stretching about 1.6 km inland and 1.6 km to the north of the nominal Hinds River" (Mitchell, 1980: p13). Numerous other drainage ditches were created, also draining where possible directly into existing gullies. In all, Grigg laid almost 150 miles (ca 240 km) of tiled field drains in order to drain water from the swamp (Stevens, 1952). This removal of an important source of water may have impacted greatly on gully development as described by Schumm and Phillips (1986) who attributed formation of the gullies to overland flow from the swamp. The swamp at Longbeach was only one of a number of isolated coastal swamps that covered a relatively insignificant part of the Canterbury Plains.

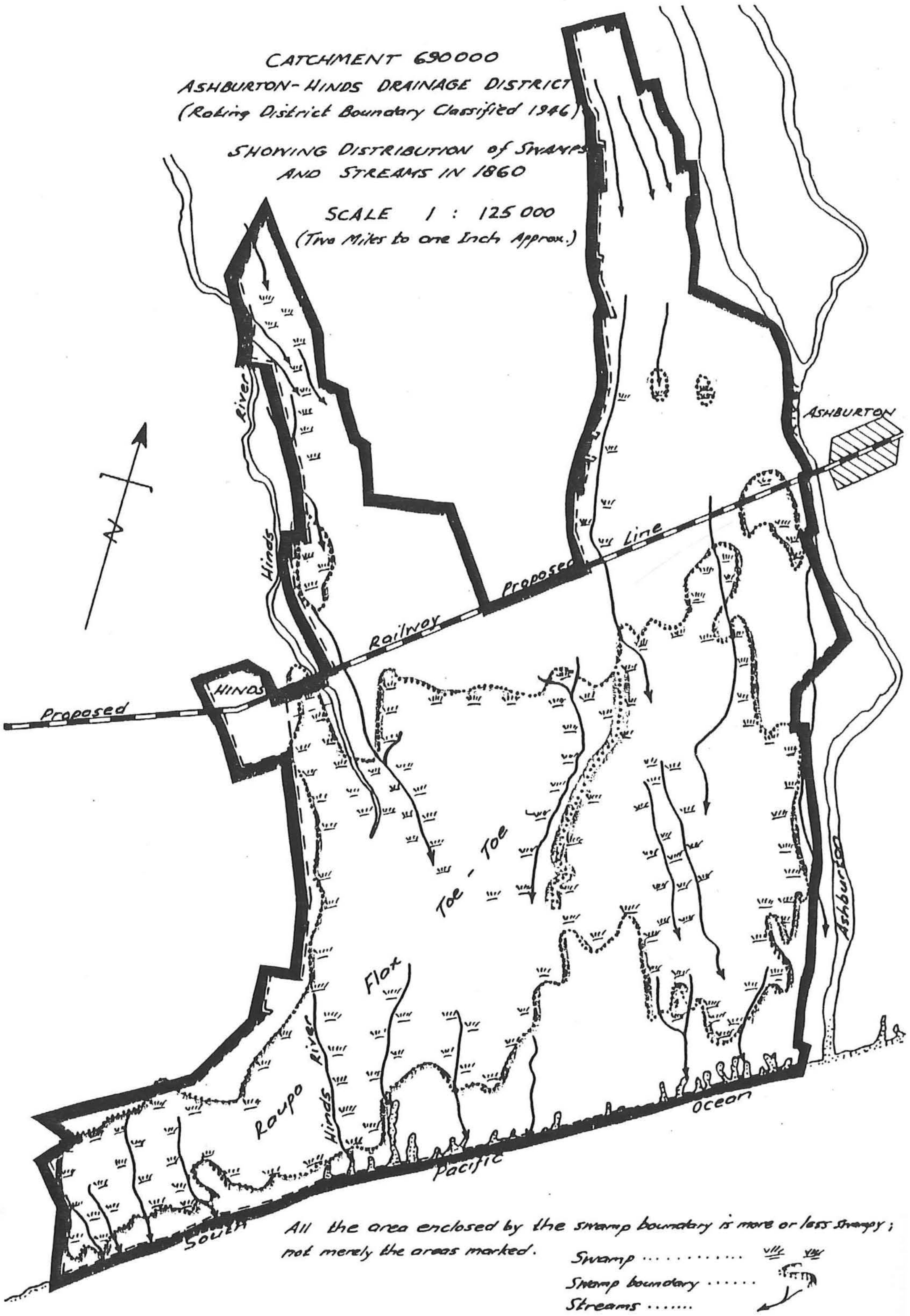

Figure 2.5: Extent of swamp dominating the area between the Ashburton and Hinds Rivers during early European settlement (from Mitchell, 1980 p14).

2.7 Summary

A brief outline to some of the historical characteristics of the physical setting has been introduced in this chapter. The natural setting in which the landforms are found has been shown to be a geologically recent and dynamic one. It is important to introduce these physical characteristics in relation to setting both temporal and spatial boundaries within which formation of the landforms may have occurred. The next chapter deals with the different processes that may have resulted in the development of the gullies. The information from these two chapters can then be linked together to set up a hypothesis for both a time and process for formation.

Chapter Three

Theoretical Framework For Gully Formation

3.1 Theoretical framework for gully formation

This chapter reviews theories of the processes thought to initiate gully erosion and the variety of gullies that can be formed by them. These theories are concerned with both surface and subsurface processes such as overland flow, rilling, pipeflow and spring sapping. This is important as it introduces some of the possible processes and types of gullies that are found in the field area.

3.1.1 Definitions

Gully erosion is one of the more obvious forms of erosion scarring the landscape and affecting land use in many places. Gully erosion occurs in many different environments and under many different conditions, which makes identification of the source of initiation a difficult task. This, the notion of equifinality, is important where a final state may be achieved by a number of different processes. Thus, any number of processes may have produced one landform, in many cases it may not be possible to distinguish between processes of formation. Davis (1927) concluded that the poverty of our language is embarrassing, as we sometimes seem to use one name for two entirely different landforms. Gullies are an ideal example for this theory as will be shown in the following discussion as 'gully' is used very broadly to describe many different landforms. Not only then, do we have the problem of equifinality, but also of accurate identification of the landforms themselves. According to Whittow (1984 p.240) a gully is a "small but deep channel or ravine formed by fluvial erosion but not permanently occupied by a stream". No quantitative measure has been given as to how large the channel must be before it becomes a gully. Many writers interchange between the use of rills, gullies and valleys with no definition given. The use of 'fluvial' in this definition is also a problem as it implies the work of a river system. This need not be the case. As will be shown, there are many alternative sources of water for the initiation of erosion.

Imeson and Kwaad (1980) used a depth of 50cm as an arbitrary criterion to differentiate between rills and gullies, although they acknowledge this isn't an ideal measure. They provided no account of how they acquired this figure or supply a preferred alternative. At the other end of the spectrum, a valley is described as "a linear depression sloping down towards a lake, sea or inland depression. It is initially created by fluvial erosion"

(Whittow, 1984 p.566). Again, there is no definition of size, only a reference to fluvial activity.

Imeson and Kwaad (1980) gave a four-step gully definition characterised by:

1. concentration of water, mostly (but not necessarily) as a result of direct or indirect disturbance of the hydrological cycle by man
2. mostly limited to unconsolidated slope deposits, weak shales and deeply weathered soils which are easily eroded
3. only intermittently occupied by flowing water; and,
4. no simple relationship between the slopes above a gully and the gully itself.

They add that gullies are recent features of the landscape that at some time experienced rapid growth.

Alternatively, Burkard and Kostaschuk (1995) distinguish between natural and anthropogenic causes of gully initiation and evolution. Natural factors identified in this study include climate change, catastrophic storm events, isostatic rebound and tectonic uplift or base level lowering. Anthropogenic factors were shown to include removal of vegetation or deforestation, overgrazing, artificial drainage and the development of roads and paths. However, the two groups of factors are closely related though, for example, a change in vegetation cover need not be due to an anthropogenic impact. With these factors in mind, the following discussion examines factors influencing gully development and the types of gullies that result.

3.2 Surface Processes

This section deals with processes occurring at the land surface in relation to the initiation of gully erosion. The processes of particular pertinence to this study are rainsplash, overland flow and rilling.

3.2.1 Rainsplash

Rainsplash erosion is the process where the impact of raindrops on the surface displaces soil particles. Individual raindrops are not noteworthy but collectively they can initiate high rates of erosion. Ellison (1948) speculated that on some soils and terrains, rainsplash erosion could account for up to 90% of erosion within heavy rain events. Ellison was the first to account for rainsplash erosion and acknowledge the damage it can achieve. Raindrops, on impact with the ground, break up sending tiny particles of soil with the droplets back into the air. A raindrop has two functions; one is a destructive force causing displacement. The other is a wetting agent, changing the properties of the soil (Cruse and Larson, 1977). Displacement of soil, due to this process, generally occurs over a number of events, resulting in the mass loss of the topsoil layer. This is really only significant on slopes where the gravity component carries displaced sediment downslope. In contrast on a flat surface, there would be little net displacement of sediment, as the particles would fall virtually straight back down. Rainsplash erosion is thus only favoured in situations where little runoff is generated and/or in regions of sparse vegetation cover so that raindrops impact on a bare surface. This is particularly important in agricultural areas where there are normally large areas of bare soil. However, eventually the effect of rainsplash is overtaken with the onset of overland flow.

3.2.2 Overland Flow

Overland flow can occur as a result of two processes. Firstly, when saturation has occurred (*ie* the water table has risen to the surface) or, secondly, when rainfall intensity exceeds the infiltration capacity of the soil. When either of these criteria are met, water is forced to move over the land surface. This can occur as sheet flow (or sheet wash) or concentrated flow. Sheet wash is the movement of an unconfined, thin film of water over the surface. Completely uniform sheet wash would be difficult to attain as irregularities in surface and lithology would concentrate flow. Flow concentrates along desiccation cracks and other irregularities on the surface. The movement of overland flow usually follows the topography, moving downslope and concentrating in irregularities on the surface.

3.2.3 Rilling

Concentrated flow as described above often forms rills, that are impermanent channels in the order of millimetres to centimetres in width. Once initiated rill development can proceed in one of two ways. Primarily, rills are generally seasonal landforms often being obliterated by the next storm event or cultivation. Rills tend not to form in the same positions in consecutive events as fine material has been eroded leaving a resistant layer. The alternative is that the rill will extend in width over successive events producing an ephemeral channel. Because rills develop on surface irregularities, flow will tend to concentrate in the channel producing a permanent channel. A channel is 'permanent' if it has a permanently identifiable cross-section without the presence of flowing water (Bull and Kirkby, 1997). Concentration of flow into these rills may result in extension and the occurrence of gullying. If rilling were occurring, it would be expected that evidence of this process would be found on the land surface.

3.3 Subsurface Processes

Subsurface processes involve the transport of sediment due to the movement of water within the regolith. The processes pertinent to this study are pipeflow, spring sapping and the tranmissivity and permeability of sediments.

3.3.1 Transmissivity and Permeability

The movement of water below the surface is a function of the porosity and transmissivity of the soil. Transmissivity is the capacity of soil to allow water to pass through it. When the infiltration rate exceeds transmissivity, saturation occurs (Whittow, 1984). The porosity of the soil particle determines how much water can be retained by the particle, or allowed to migrate through it. The size and degree of the connection of pore spaces between particles and inter-particle pore spaces determine permeability of the material (Duff, 1993). Permeability is determined not only by the properties of the sediment, but also by the characteristics of the water flowing through it. The amount of water and the speed at which it is flowing are important factors in determining the permeability of the sediment. Sediment with a high clay content is likely to have a low transmissivity and permeability rate as clay expands when wet and retains moisture, not allowing water to pass through. Alluvial gravel with a mixture of sediment size and large pore spaces has a high ability to transmit water. It has already been mentioned in Chapter Two that there are layers within the Canterbury Plains that are more able to allow water to move through it than others. This might be an important factor in determining the location of the gullies.

3.3.2 Pipeflow

Pipeflow is commonly referred to as 'piping' or 'tunnel erosion'. Pipeflow is the lateral movement of water as throughflow beneath the surface. Throughflow in pipes removes fine sediment out of the system leaving a hollow tunnel beneath the surface. Pipes can range in size from millimetres to meters in diameter in suitable conditions. Piping has the potential to play a significant role in gully development. Figure 3.1 presents the steps that may initiate gully erosion after pipe collapse. The removal of sediment below the surface may result in a weak layer, resulting in the collapse of the over hanging material. Further events remove the fallen material to expose a gully.

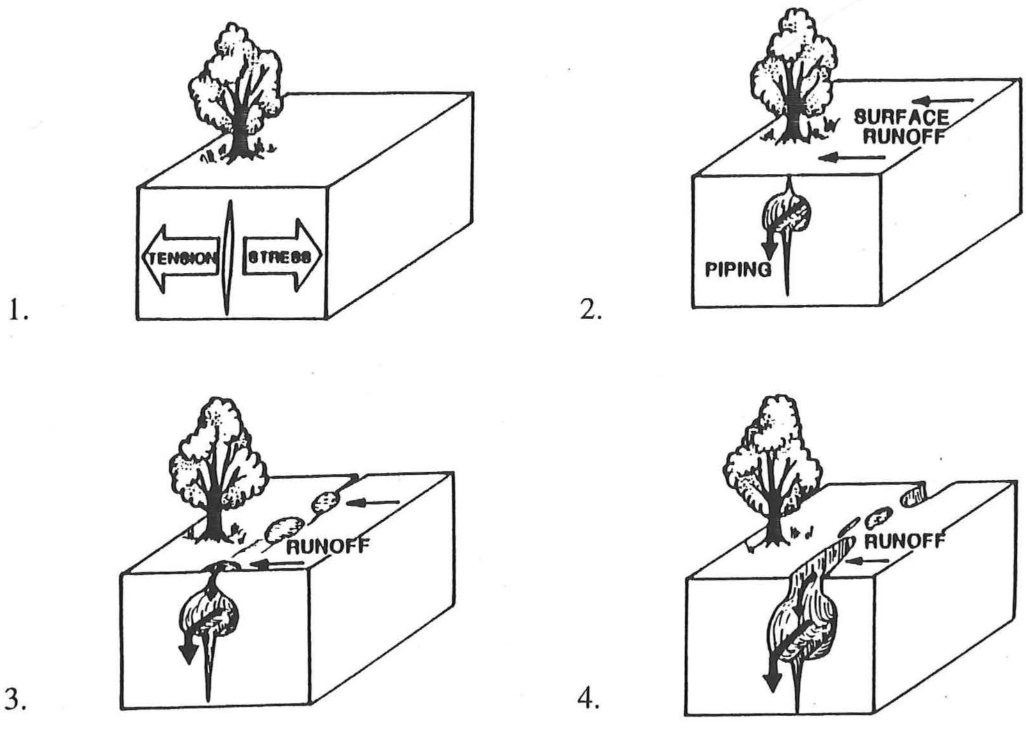

Figure 3.1: Generalised stages of gully initiation due to pipe collapse (after Pewe, 1990 p.224).

1. Lateral stresses induce tension cracking.
2. Surface runoff and infiltration enlarge crack through subsurface piping.
3. As piping continues, fissure appears at the surface as small cracks.
4. As erosion continues, the fissure enlarges and completely opens at the surface due to roof collapse.

Jones (1981) extensively reviewed the literature on soil piping. He identified four basic conditions prevalent in the literature that are required for piping to occur:

1. sufficient water either to cause drainage through cracks or to saturate a layer of higher permeability than the layer below it
2. hydraulic head sufficient to move water through a subsurface route
3. presence of a permeable or deeply cracked soil or bed rock above gully floor level
4. an outlet.

Jones (1990) associated piping with soils that have a reduced vertical permeability but which have continued lateral permeability. Schumm *et al.* (1995) and Baker *et al.* (1990) referred to a hardpan or a change in stratigraphy that results in a solid layer. In many instances piping follows pre-existing irregularities in the subsurface structure either along hollows left by decaying roots or burrows (Heede, 1971; Kochel *et al.*, 1988 and Swanson *et al.* 1989). Sparse vegetation increases the likelihood of piping as water is prone to concentrate along desiccation cracks or rills and join subsurface flow (Bull and Kirkby, 1997), but because it is subsurface flow, piping is also capable of operating in areas of complete vegetation cover (Jones, 1990). Piping generally has a seasonal aspect to it and is therefore likely to be active for only a short period of the year. However, it is still a major contributor to soil erosion and can cause significant amounts of damage over a short time frame. Piping is normally associated with low slopes of 3-15 degrees. Flatter than this and the flow of water becomes sluggish, any steeper and runoff will occur as overland flow rather than subsurface flow (Ballie *et al.* 1986).

An important factor pertaining to piping is that they require an upper and lower stable layer to provide roofing, reducing the occurrence of collapse (Jones, 1971). Collapsed pipes may cause surface irregularities as the surface layer slumps to fill the existing cavity. In turn this can result in a concentration of flow in these irregularities, eroding surface material and causing gullying. If piping were a process initiating gully development, it might be expected that remanets of pipes would be found around the gullied area.

3.3.3 Spring Sapping

Spring sapping involves the return of subsurface flow to the surface. Dunne (1980) attributes the development of channel networks to spring sapping and Baker *et al.* (1990) described spring sapping as occurring where groundwater outflow undermines slopes resulting in the development of valleys. Spring sapping occurs as concentrated groundwater discharge, concentrating in depressions, enhances pre-existing irregularities and flow into these regions. This enhances headward erosion, which in many cases intercepts other areas susceptible to sapping, generating tributaries, or extensions aligned with structures from other zones. This will eventually form a network of systems, all competing with each other for available groundwater (Baker *et al.*, 1990). Figure 3.2 indicates the factors facilitating sapping at a variety of scales showing the complex nature of this process. Sapping facilitates basal undercutting where processes of erosion will remove sediment from the base of a slope resulting in failure, the scale of which is dependent on the factors included in Figure 3.2.

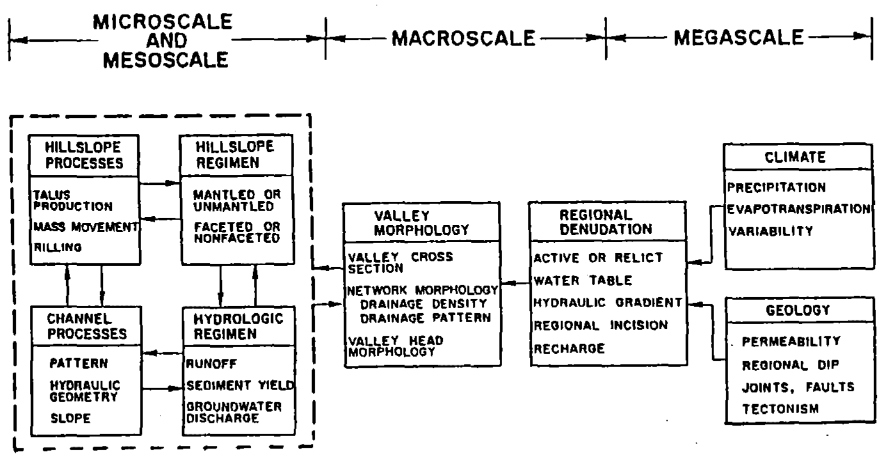

Figure 3.2: Important factors in valley morphogenesis by spring sapping at a variety of scales. (From Baker et al., 1990 p.236).

Figure 3.3 depicts how a spring head can be extended due to a concentration of flow to form a drainage network. Groundwater in Figure 3.3b converges on an abnormality caused by a collapsed pipe or some other irregularity at the land margin for instance along a steep face. In Figure 3.3c, groundwater flow has concentrated around the head and has extended away from the land margin, pirating (or capturing) groundwater flow from surrounding areas. Flow concentrates intensely around the sapped area due to a localised lowering of the ground surface, increasing the probability of further piping, extending tributaries off the main trunk until growth of the network has outgrown the supply of groundwater available for sapping.

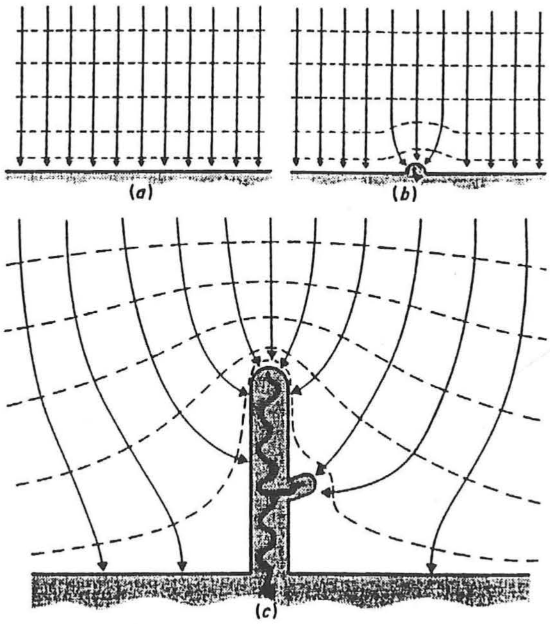

Figure 3.3: Plan view of groundwater flow during extension of spring heads to form a drainage network. Solid arrows are flow lines. (From Dunne, 1980 p.228)

3.4 Gully Growth and Classification

It is widely recognised that gullies that may superficially look similar (on the surface) are in fact genetically different. Gully type, shape, size and process may vary between environments making identification difficult, especially when trying to classify between settings. It is often the case where evidence of the initial process of formation has been eradicated due to extension resulting in a landform in no manner resembling its mode of formation. Valley development following rilling or pipe collapse are good examples of this.

Glock (1931) identified two stages in the evolution of a drainage network, those being extension and integration (Figure 3.4). Extension can be viewed as the 'birth' of the drainage system. The early phase of a general pattern of growth is aimed at elongation and elaboration of first order channels in the network. Glock's second stage, integration, was characterised by three phases: abstraction, absorption and adjustment. Abstraction, like piracy is where a secondary stream is overtaken by the primary source as they compete for the same source of water, thus, abstracting water from its own tributaries. This leads to absorption where the smaller tributaries that have been pirated disappear into the main channel network. By the third phase of this stage (adjustment) the channel is attempting to make its way to base level (sea, lake or river) by the easiest route possible determined by the general slope of the drainage area.

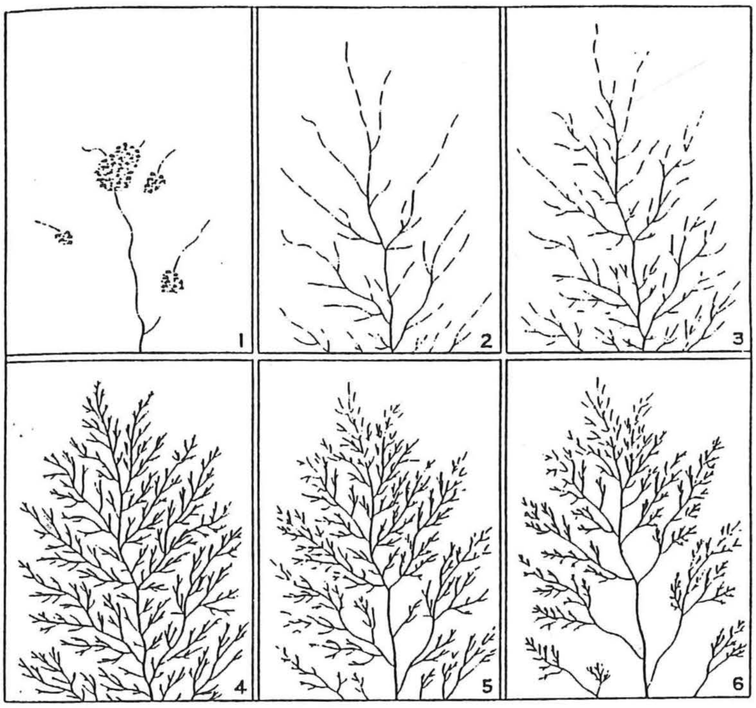

Figure 3.4: Diagrammatic summary of the development of a drainage system. Parts 1-4 show extension (1: initiation, 2: elongation, 3: elaboration, 4: maximum extension). Parts 5 and 6 represent integration. (Glock, 1931 p.481).

According to Dunne (1980), the general influence on spacing of channels is the competition for subsurface flow. Divergence of subsurface water causes a local lowering of the hydraulic gradient and probably a local decrease of erosion resulting in a stabilising effect on the ground surface between channel indentations. The extending valley pirates subsurface water generating a branched hierarchical system leaving the area between channels relatively untouched.

The following researchers classified gullies based on their appearance. Leopold and Miller (1956 cited in Nordstrom, 1988) classify gullies as continuous and discontinuous. A discontinuous gully starts at any point on a slope as a headcut or pipe due to a concentration of runoff in a break in the surface. A continuous gully starts as a series of rills generally higher up the hillslope.

Ireland *et al.* (1939) classified gullies of the Piedmont of South Carolina into six categories as can be seen in Figure 3.5. A description of the six categories can be found below.

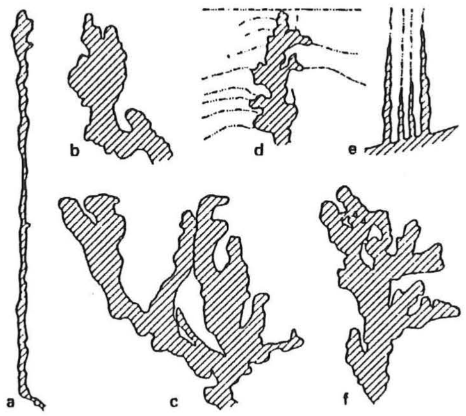

Figure 3.5: Characteristic gully forms (Ireland *et al.* 1939).

a) Linear gullies are long, narrow and have few tributaries.

b) Bulbous gullies are broad and spatulate near the head but may be more linear in the lower reaches. These often have a semi-circular or amphitheatre shaped head with small tributaries or rills entering from the sides.

c) Dendritic gullies are formed of many branching tributaries with semi-circular or amphitheatre shaped heads.

d) Trellis gullies develop on gentle slopes and are made up of tributaries or branches entering the main channel at angles approaching 90°.

e) Parallel gullies are composed of two or more parallel tributaries emptying into a main gully. Eventually, capture by another tributary is likely to destroy this parallel pattern.

f) A composed gully is a combination of any two or more of the above.

Table 3.1: Sets of conditions characterising particular gully types (Imeson and Kwaad, 1980 p.432)

Gully type	*Gully cross section*	*Position in landscape*	*Principal source of runoff*	*Materials in which gully is developing*	*Favourable conditions*
Type 1	V-shaped	Anywhere, except valley bottoms, where runoff becomes concentrated	Overland flow	Relatively resistant weathering products of impermeable parent materials, B horizons of deep soil profiles. The resistance of the material does not decrease with depth.	Intense rainfall, poor soil structure, steep slopes, poorly built terraces and tracks
Type 2	U-shaped	Anywhere in land-scape except valley bottoms	Overland flow with a contribution of subsurface water of lesser importance; occasional seep caves at head	Relatively little resistant weathering products or slope deposits which do not increase in resistance with depth.	Dispersive soil materials, sub humid climate with pronounced wet and dry seasons
Type 3	U-shaped	Anywhere, but usually on pediments and gentle lower slopes	Subsurface flow predominates, as is apparent from piping	Weathering products and slope deposits as for type 2	Dispersive soil materials are essential; further as type 2
Type 4	U-shaped	Valley bottoms	Overland flow, mainly from tributary gullies, and subsurface flow	Alluvial and slope deposits	Semi arid climate, lack of valley bottom vegetation, dispersive materials

De Ploey (1974) identified three classes of gullies in Tunisia, those being axial, digitate and frontal. Axial gullies consist of V or U-shaped channels with a single headcut and constant width extending up the channel. Digitate gullying retreats with several headcuts. Frontal gullies generally start from river banks and vertically stable gullies with a nearly parallel slope and scarp retreat (this is the extent of description given).

Brice (1966) classified gullies according to their location in the landscape as valley-head, valley-bottom or valley-slope. Similarly, Imeson and Kwaad (1980) take classification further, as can be seen in Table 3.1, and distinguish between four types of gullies grouped according to their cross-section, type of runoff and position in the landscape. They justify their classification system by stating that any classification system must be formulated in such a way as to make determination of class as simple as possible. Preferably determination should be able to be made in the field under any conditions, that is, without waiting for a rain event or identifying a change in morphology over time. They also suggest that gullies may be transitional (between two types) or that more than one type may occur within a single gully system.

Other classifications are based solely on cross-sectional shape and generalisations made about the processes that produce each shape. Figure 3.6 gives examples of cross-sectional shapes identified by two basic shapes, V and U, determined by the resistance of the soil and the processes operating on it.

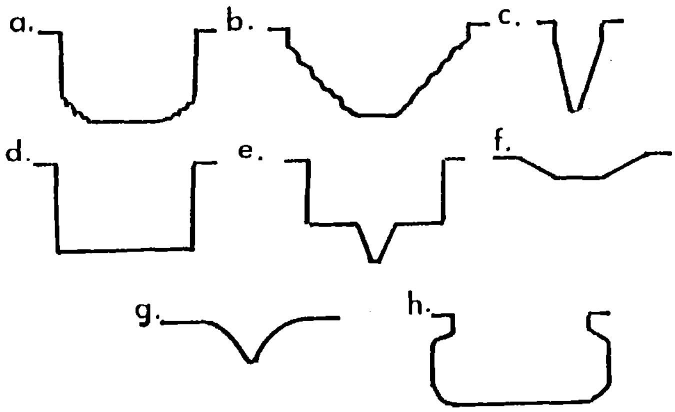

Figure 3.6: Examples of cross-sectional gully shapes (Nordstrom, 1988 p.13).

U-shaped gullies occur where the subsoil is deep and erodible. The upper limits of the walls are close to vertical due to collapse. The fallen material accumulates around the bottom, depending on the transporting capacity of the flow. If the transporting capacity of the flow is great, the material will be removed as in Figure 3.6a, leaving only small amounts of material accumulated at the base of the slope. If the capacity of flow is low, the material will build up as a talus slope giving the gully a trapezoidal shape (Figure 3.6b). V-shaped gullies such as shown in Figure 3.6c, occur in relatively resistant material. Rectangular shaped gullies occur when a resistant surface is met (Figure 3.6d). Downcutting in such gullies leads to the initiation of a secondary gully within the first as in Figure 3.6e. Coarse sediment is likely to result in a wide, shallow gully such as that in Figure 3.6f. Extensive sheet erosion and rilling on the gully walls may result in a V-shaped gully with convex sides (Figure 3.6g). Resistance of a layer above an erodible sub-layer may result in overhanging ledges as in Figure 3.6h.

3.5 Appropriateness of Classifications

In regard to the appropriateness of utilising a classification in order to distinguish between types of gullies, it seems necessary to combine a number of the classifications discussed due to the number of different processes that may be occurring. It would not be suitable to try to classify gullies in the study area according to their cross-section, plan form or position in the landscape alone. Instead, it is proposed here to use Nordstrom's cross-sectional classification (Figure 3.6) along with that of Ireland *et al.* (1939) (Figure 3.5) and their classification based on gully form. Comparing these with the set of conditions assigned by Imeson and Kwaad (1980) (Table 3.1), it will be possible to include a wide variety of characteristics pertinent to the grouping of landforms into classifications. Nordstrom's cross-sections, although broad, are easily identified and applied to gullies making ordering by this method relatively simple. Ireland *et al.*'s classification by categories should allow a general ordering of gullies into groups. It is likely then that as a result of using a combination of classifications, a number of different groups may be identified within the study area to reflect the diverse nature of the gullies.

Chapter Four

Methods & Results

4.0 Methods and Results

This chapter sets out the methods used in this research. These include topographic mapping, aerial photograph interpretation and ground truthing. Results obtained through these methods are presented here but discussion is reserved for Chapter Five.

4.1 Methods

Maps and photographs are useful sources of information in geographical interpretation of the landscape. Both of these are used in this study to investigate the gullies.

4.1.1 Mapping

The lack of previous investigations into these gullies means that the first objective of this thesis is to examine their distribution along the coast. It has already been established in Chapter two that the gullies are found predominantly between the Rakaia and Rangitata Rivers (Figure 2.1). Nevertheless, the physical location of the gullies within this area is not the only important factor of their distribution. Also of importance are any spatial trends in relation to the characteristics of the gullies (size is one parameter of interest, another is the clustering of gullies of similar sizes). To examine these features, the gullies were mapped using the NZMS 270 series 1:25000 maps (K38B, L37C&D, L37B). Using this technique in conjunction with other photographic and mapping techniques discussed below, geomorphic maps were produced which clearly show the distribution of gullies both within the selected area and in relation to each other.

4.1.2 Vertical Aerial Photographs

Aerial photographs are another effective way of examining the gullies on a large spatial scale. Aerial photographs have been used in this study to examine a number of different parameters pertaining to individual gullies. A set of 1:16000 (approximately), 1952 black and white aerial photographs was used for this study (refer to Appendix 1 for a full list of photographs). A preliminary examination of the aerial photographs and topographical and geomorphic maps, later ground truthed in the field, resulted in choice of seven gully characteristics that could be easily extracted from the photographs, namely length, shape, orientation, presence/absence of a stream, branching, channel and vegetation cover. These terms are ambiguous so working definitions for this study are as follows.

Length was measured in mm and is the distance on the photograph between the mid-point of the mouth of the gully and the furthest tip at the head. If there was more than one head, the furthest inland point was taken.

Stream indicates whether there is an identifiable channel carrying flow in the photographs.

Vegetation is the presence of any type of vegetation cover be it grass, shrub or forest. Vegetation coverage gives an indication of gully stability, as established vegetation is not likely to have formed on an eroding surface.

Orientation is the angle at which the gully axis lies in relation to the coastline. This is measured in degrees from the middle of the mouth, in the direction in which most of the gully is lying.

Channel refers to the gully having a flat, identifiable bottom surface.

Branching is whether the gully has any tributaries off the main channel; no record was kept of how many branches were observed.

Shape is a reference to the cross profile of the channel.

Each gully was examined under a mirror stereoscope in order to extract the seven characteristics mentioned above.

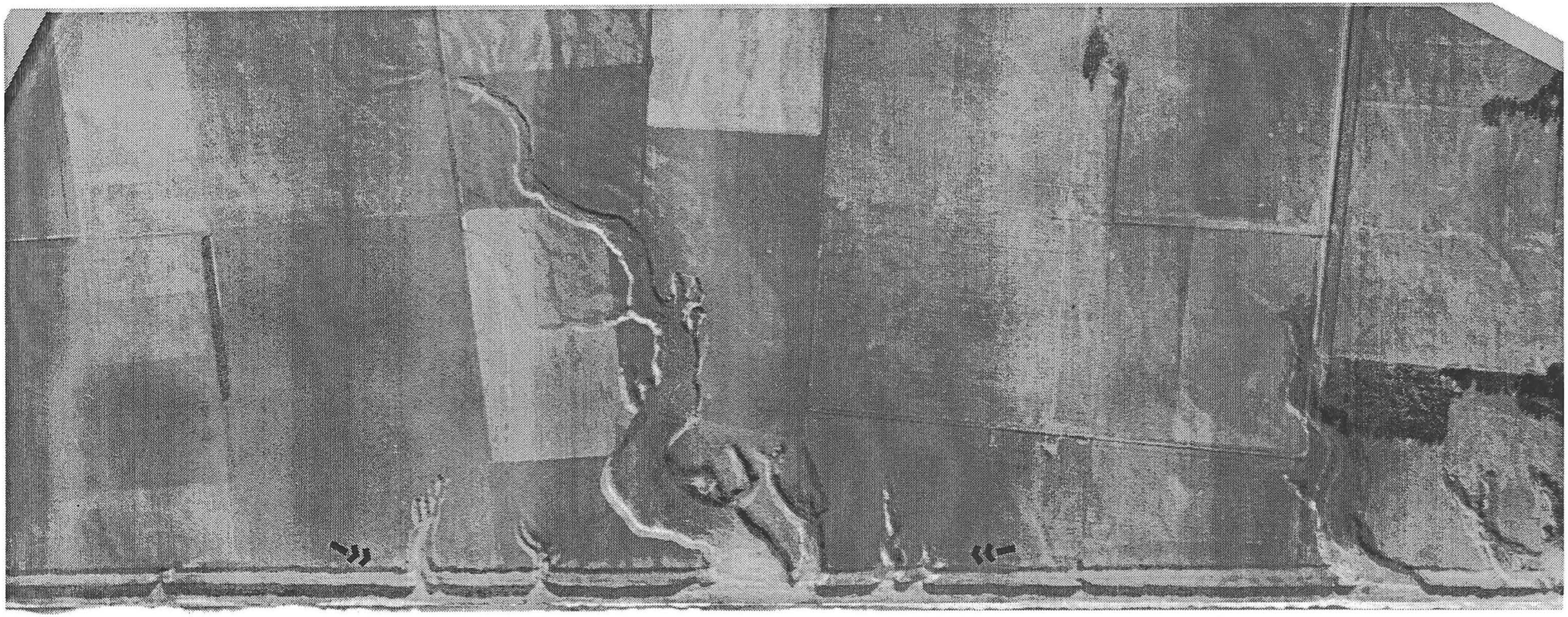

Plate 4.1: 1952 and 1996 photographic overlay of gully number 283.

In addition, aerial photographs from 1952 were compared with others taken in 1996. This was done to identify any changes that may have occurred during recent times. The 1952 photographs have a scale of 1:15960 while the 1996 photographs are 1:27000. The scale of the photographs was manipulated using 'PhotoShop'; a computer based graphic package able to manipulate images. This package was used in order to facilitate the most accurate comparison possible. By making one photo transparent it is possible to overlay the different years to note particular changes to the gullies and the adjacent coastline. An example of this can be seen in Plate 4.1.

An alternative method of comparing aerial photographs is demonstrated in Plates 4.2 and 4.3. Instead of overlaying the time series, specific areas have been identified and displayed side by side. Once the scales have been adjusted, this sort of manipulation is a relatively quick and simple method of comparing identical features on sequential photographs. Historical maps and charts, along with oblique photographs, were also used to cross-examine particular changes over a longer time period.

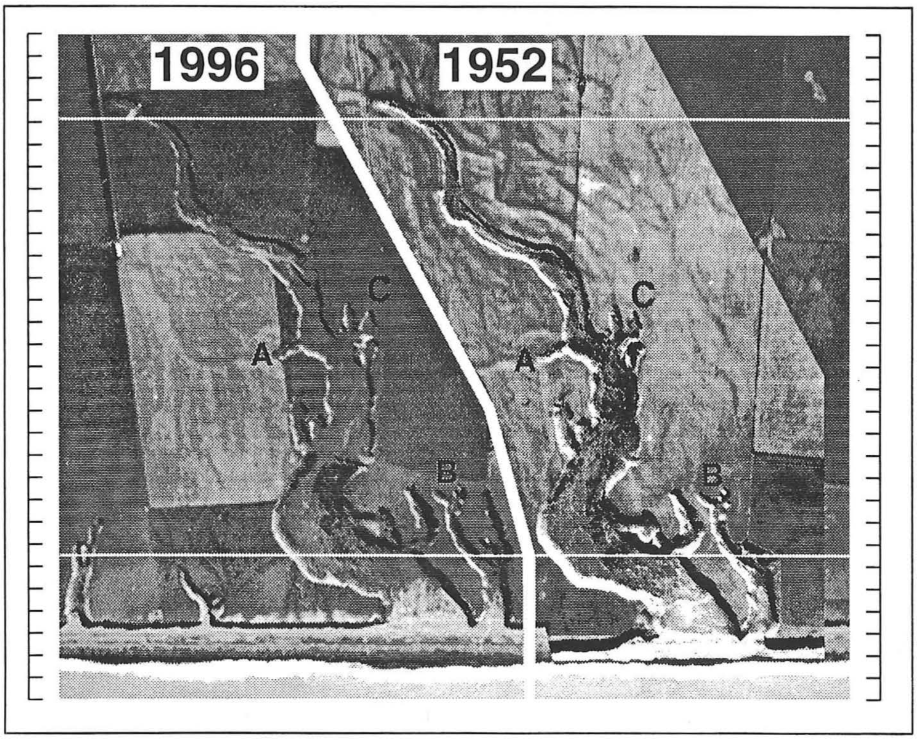

Plate 4.2: 1952 and 1996 comparison of gully number 283.

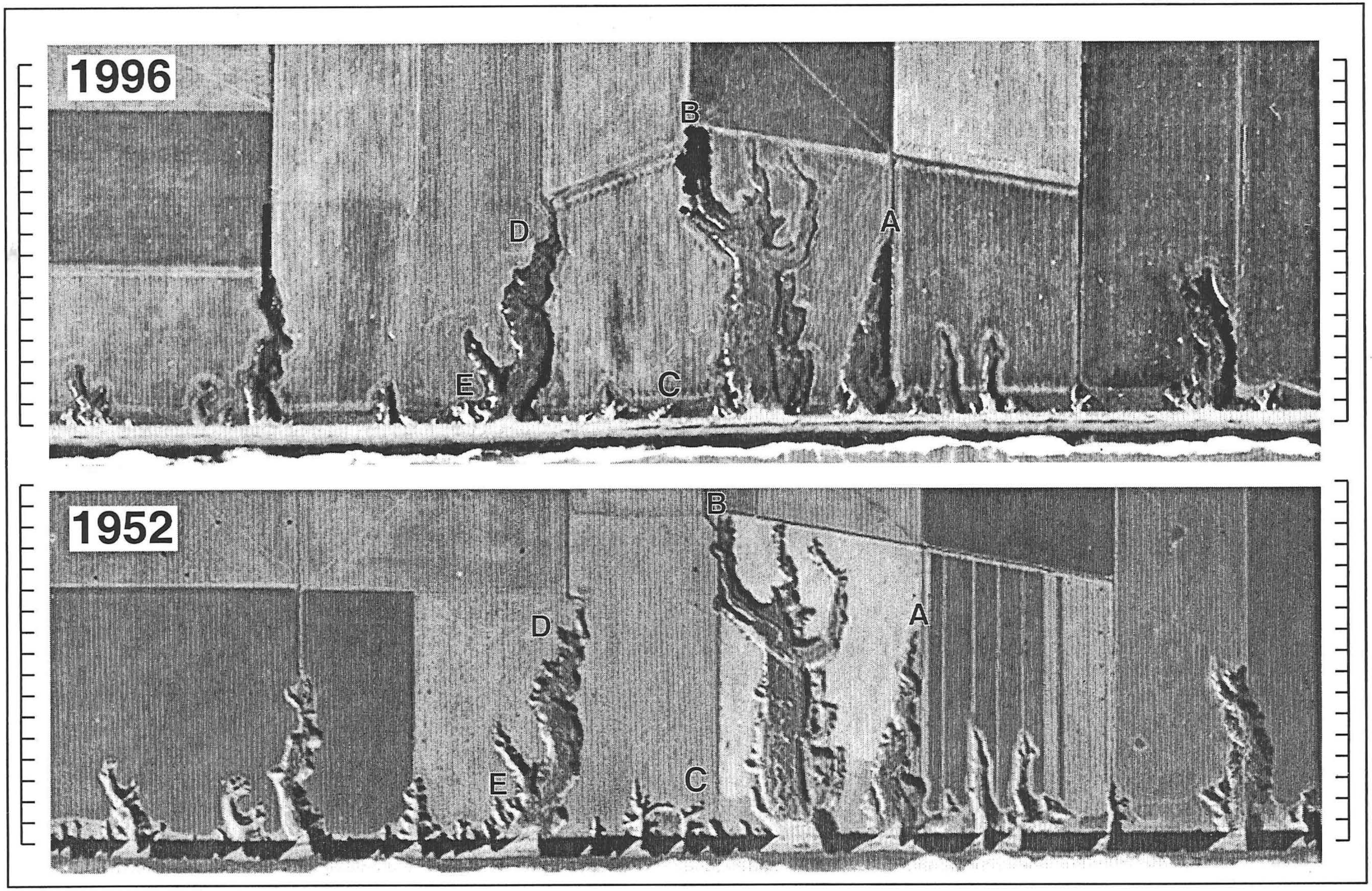

Plate 4.3: 1952 and 1996 comparison. Gully at B is number 200.

4.1.3 Field Work

Although a substantial part of this analysis has been based on aerial photographs, not all features can be seen on these photos. Field investigations complement theories established through the literature search and examinations of the aerial photographs. Fieldwork included both quantitative measurements and a variety of qualitative observations. Observations made in the field may take on a number of forms.

A substantial number of oblique photographs were taken both from the air, and on the ground. A Piper 181 aircraft was used to take oblique aerial photographs allowing for an overview from a variety of angles at differing altitudes. Photographs taken from the ground, in some cases from within the gullies, also allowed scrutiny from a variety of positions. These photographs have proved to be valuable as a tool for observing and displaying the physical characteristics of the gullies. Oblique photographs can portray a lot more information than is readily available in topographic maps and vertical aerial photographs, or than can be seen on site.

Field research also consisted of using a GPS (Global Positioning System) or Total Station to traverse the gullies in order to obtain numerical data. This data was produced as an X, Y, and Z coordinate to obtain distance and elevation from a fixed location. The Total Station is more accurate over smaller distances as the GPS, once differentially corrected, can have an error of approximately ± 0.5m. This error is however acceptable at the scale and the purpose for which it was being used. Over larger distances, the GPS is more appropriate as it is easily transported in a backpack.

Other field methods included an approach of 'sitting and looking'. Discussion held within the field also proved to be invaluable in obtaining a fresh perspective and different ideas.

4.2 Results and Data Analysis

4.2.1 Geomorphic Mapping

As previously mentioned, geomorphic maps were produced for the area between the Rangitata and Rakaia Rivers (Figure 4.1 a, b and c). It is apparent from these maps that the largest gullies are clustered around the areas of the Hinds River and between Wakanui Creek and just south of the Ashburton River. There are however errors with the topographic maps from which the geomorphic maps were produced in that they are not accurate at the scale which the study required. They do though give a good outline as to where the gullies may be situated, and, when compared with information gathered from all the other methods used, result in a reasonable interpretation of the location of the gullies.

4.2.2 Aerial Photograph Interpretation

Results for most parameters in the aerial photograph examination are in the form of yes/no answers or in the case of shape either U or V. Measurements were taken for the length of the gullies and orientation (results in Appendix 2). Table 4.1 presents a break down of the information obtained in this analysis.

Table 4.1: Vertical Aerial Photograph Examination (n=318)

	U	V	Not Sure
Shape	124 (38.99%)	170 (53.46%)	24 (7.55%)
	Yes	**No**	**Not Sure**
stream	10 (3.15%)	296 (93.08%)	12 (3.77%)
vegetation	128 (40.25%)	170 (53.46%)	20 (6.29%)
channel	116 (36.48%)	174 (54.72%)	28 (8.80%)
branching	136 (42.77%)	181 (56.92%)	1 (.31%)

The analysis of aerial photographs summarised in Table 4.1 was based on the number of counts within each category, failing to keep the characteristics of each gully grouped together. It was therefore unknown from this inquiry which gullies had which characteristics and the relationship between these characteristics. Because of this, the exercise was repeated.

In the second analysis, the gullies were assigned identification numbers starting at the Rangitata River, going northward towards the Rakaia River (throughout the thesis, gullies are referred to by these identification numbers). In this investigation, only 298 gullies were counted where 318 were counted in the first analysis. This reflects the subjective nature of analysing aerial photographs. It is important to note that only approximately 90 gullies are identified in Figures 4.1a, b and c, even less are identified on the 1:50000 topographic maps where only 75 could be recognised. As mentioned previously, this is in accordance with the accuracy of the scale involved.

This second analysis incorporated a number of refinements. A break down of results can be seen in Table 4.2. The stream designation has been changed from being the *actual* presence of water in a channel to the *potential* to carry flow in a rainfall event. The analysis used 1952 photographs, an instant snapshot of only one set of conditions. The *potential* for the gullies to carry flow during an event is the important factor, as this will indicate whether the gully has the *potential* to erode through fluvial action. Ultimately, any indentation in the landscape has the potential to carry water if the flow were large enough; however, this refers to an obvious channel being situated in the gully. The channel category has been dropped, as the occurrence of a channel will be picked up between stream and shape of the gully. Added to the investigation was information on the drainage order of the gully. The number of branches a gully has is recorded and its order ranked from this. Order was obtained by using the Strahler method whereby two first order streams meet the order then increases to a second order. Order can only increase where two branches of the same order meet (Leopold, Wolman and Miller; 1964, Whittow; 1984). It is generally quite clear what is a branch and what is not. However, in some cases, the distinction is not so clear. In most cases discretion of the author distinguished between branches and "bumps" or notches off the side of the gully, although as a rule of thumb, the branch length would be twice as long as the mouth of the branch where it joins the main channel. This is an error encountered when interpreting aerial photographs and is exacerbated when dealing with objects that are mm in scale. The characteristics recorded for each gully in this second analysis are listed in Appendix 3 and the locations of the gullies can be inferred from Figures 4.1a, b and c.

Table 4.2: Vertical Aerial Photograph Examination (n=298)

	U	V
Shape	146 (49%)	152 (51%)
	Yes	**No**
Stream	84 (28%)	214 (72%)
Vegetation	161 (54%)	137 (46%)
Order	**1**	202 (68%)
	2	82 (27%)
	3	13 (4%)
	4	1 (1%)

Branches		
	0	202
	1	9
	2	38
	3	23
	4	10
	5	5
	6	1
	7	2
	8	2
	9	1
	10	2
	11	1
	12	1
	13	0
	14	0
	15	1

Categorising the gullies into two groups (U and V) based upon shape is not ideal as this generalises the diverse array of gullies discussed in Chapter One into only two groups. It is however a generally accepted form of grouping gullies (Imeson and Kwaad, 1980; Nordstrom, 1988). The terms U and V shaped gullies are associated with the shape and slope of the sidewalls of the gully in relation to the bottom channel. The U and V shapes are descriptions of the cross-profile where U shaped gullies have steep, near vertical walls and the V shaped gullies have sloping walls. In this case, U and V are distinguished differently with reference to the width of the gully floor. U shaped cross sections include a flat floor; the sides of the gullies are sloping, more in keeping with Figure 3.5b. V shaped gullies have steep sides but with no identifiable flat channel surface. The sidewalls are generally near vertical (as in Figure 3.5d) except where talus slopes form as the result of slumped material accumulating on the gully floor.

4.2.3 Errors in Aerial Photographic Interpretation

There are a number of inaccuracies involved in obtaining information off photographs of this scale (scale is approximately 1:16000). These fall into two broad categories, errors with the photographs themselves and in interpretation. Errors concerned with the photographs themselves include shrinkage of the paper and film, scale, and in the actual taking of the photos (Moffitt, 1969). Scale errors increase away from the principal point (centre) towards the edges of the photograph. Due to the processes involved in taking aerial photographs, this aspect can't be helped, although it can be minimised by using only the centre of the photos (Smith and Zarillo, 1990). Errors with interpretation can vary considerably between observers. In this case, measurements were taken to the nearest estimated $\frac{1}{4}$ of a mm. There are many other potential inaccuracies involved with the flight path of the aircraft, camera and atmospheric interference, but these will not be examined here as they are not relevant at this scale of investigation.

Avery (1977) refers to the process of image interpretation as "highly dependant on the capacity of the mind to generalize". This may be the case, but it may also be argued that the interpreter needs to identify precise details. Photo interpretation is often seen as an art form rather than an exact science due to the subjective judgement that is required by the interpreter. In fact, it is both (Avery, 1977). In many instances, two interpreters can obtain completely different results based on the way in which they view the images and their experience. One interpreter's diagnosis may also vary over time due to these same factors. A large discretionary element is therefore present in this form of examination due to the above factors. Even given these considerations, aerial photograph interpretation is still one of the most efficient ways of examining the landscape on a large scale, especially if access to the area is limited. Errors have been reduced by ground truthing, and with the use of oblique photographs and topographic maps.

4.3 Gully Characteristics

This section begins by looking at the gullies on a broad scale, examining their length, orientation and branching. It then comes down in scale to examine particular features of the gullies in specific areas.

4.3.1 Results of Tallied Gully Characteristics

Figure 4.2 diagrammatically represents the orientation of gullies to the coastline. The number of gullies within each category is represented by the length of the line which is proportional to the number of gullies within the measured angle. Figure 4.2 clearly shows a tendency towards the 90° angle.

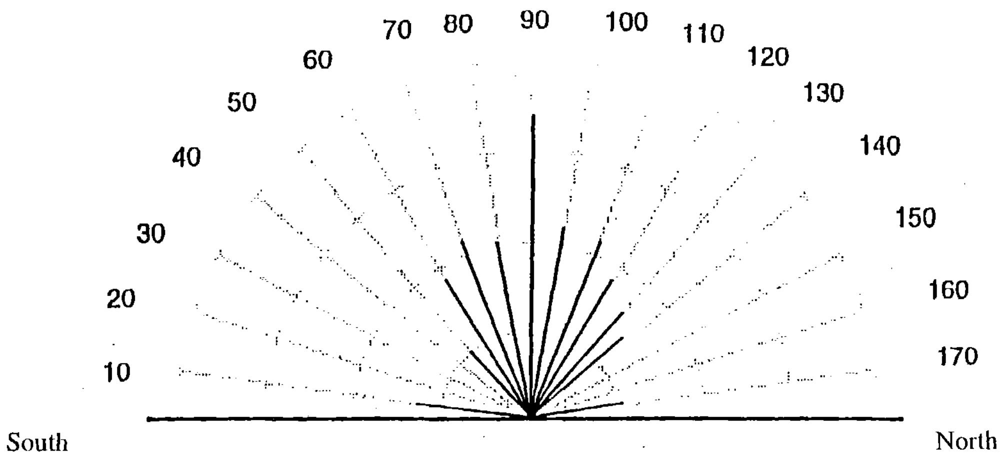

Figure 4.2: Diagrammatic representation of gully orientation. The baseline represents the coastline. Scale is logarithmic from 0 at the centre to 1000 at the outside edge.

Figure 4.3 shows the length of gullies grouped against gully identification number. Because the gullies occur almost continuously along the coast, this effectively is gully length against distance. It is obvious that the largest gullies are situated around the areas of the Hinds River, Ashburton River and Wakanui Creek. The number of branches per gully has been graphed in Figure 4.4, clearly showing that nearly 70% of gullies have only the one main channel with no branching.

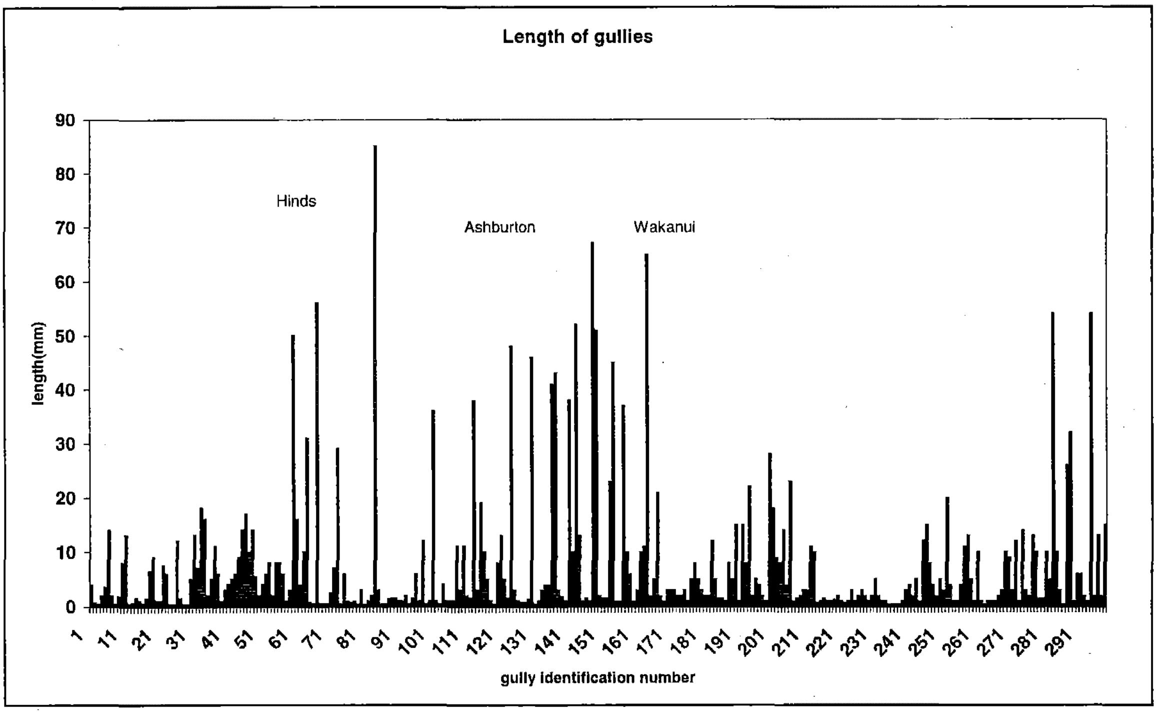

Figure 4.3: Gully length in mm as observed from 1952 aerial photographs

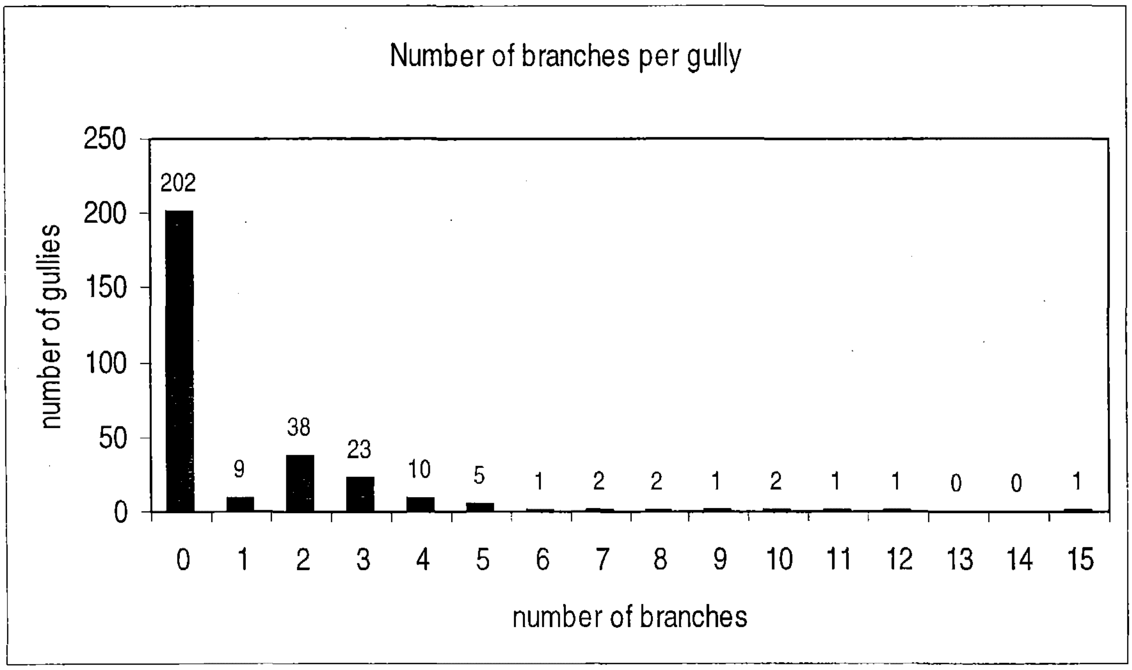

Figure 4.4: Number of branches per gully as observed from the 1952 aerial photographs

4.3.2 Chi^2 Tests

Data displayed in Table 4.2 were used to calculate chi-square tests to determine whether there is a relationship between some of the parameters tested, or whether the characteristics of the gullies occur independently from one another. Four different variables were tested against shape those being length, order, angle and vegetation, the results of which can be seen in tabulated form in Tables 4.3 to 4.6 (actual workings of the tests are in Appendix 4). These parameters were chosen to provide an indication of the development or maturity of the gullies. Gullies that are large or vegetated are likely to be more "mature" as they would have needed more time to develop to this extent. Gullies with a higher order are predominantly larger, consequently are more likely to be U shaped. This occurs as order increases with the number of branches. Larger gullies are more inclined to have branches, therefore also have a greater order. The bold numbers indicate figures we would expect to find according to the laws of probability pertaining to the tests. All values are taken at the 0.1 significance level (refer to Ebdon; 1977 and Norcliffe; 1977 for a further explanation of Chi^2 tests).

Table 4.3: Chi^2 Test; length against shape

Length	U shape	V shape	Total Number
0.4-2	7	103	110
	53.89	**56.11**	
2.1-10	79	48	127
	62.22	**64.78**	
10.1-20	34	0	34
	16.66	**17.34**	
20.1-85	26	1	27
	13.23	**13.77**	
Total	146	152	298

$\chi 2$ = 148.42

Table 4.4: Chi^2 Test; order against shape

Order	U shape	V shape	Total Number
1	63	139	202
	98.97	**103.03**	
2	69	13	82
	40.17	**41.83**	
3&4	14	0	14
	6.86	**7.14**	
Total	146	152	298

$\chi 2$ = 80.762

Table 4.5: Chi^2 Test; angle against shape

Angle	U shape	V shape	Total Number
0-79	0	31	31
	15.19	**15.81**	
80-100	117	120	237
	116.11	**120.89**	
101-180	29	1	30
	14.7	**15.3**	
Total	146	152	298

$\chi 2$ = 57.073

Table 4.6: Chi^2 Test; vegetation against shape

Vegetation	U shape	V shape	Total Number
Yes	142	19	161
	78.88	**82.12**	
No	4	133	137
	67.12	**69.88**	
Total	146	152	298

$\chi 2$ = 215.40

All parameters tested reveal a strong dependant link with the shape of the gully by greatly exceeding the critical values. It could therefore be concluded that all four parameters tested are significantly associated with the cross-sectional shape of the gullies.

The Chi^2 tests indicate a strong preference for the V shaped gullies to be smaller, first order channels. V shaped channels also tend to not be vegetated. A majority of gullies, both U and V lie between 80 to 100^o to the coastline. An interesting feature that comes out of table 4.5 is that no U shape gullies are oriented about the 0-79^o or V shaped gullies at the 101 to 180^o. These aspects will be examined further in the next chapter.

4.4 Case Studies

4.4.1 Photograph Manipulation and Interpretation

The main, large gully in Plate 4.2 is gully number 283, note points A, B and C. These points are for observational purposes. Over the 44 year period, little, or no change has occurred in respect to extension of the gully. If the gully was actively evolving, it would be expected that it would occur in areas such as these (A, B and C). The only changes, however, that occurred over the 44 year period was an increase in vegetation and erosion of the mouth due to coastline retreat.

Plate 4.3 depicts much the same findings as found in Plate 4.2. The gully labelled B in Plate 4.3 is number 200. The only real change has been an increase in vegetation and a retreat of the coastline. There are no irrigation outlets in this area which is another way in which gullies may extend. It can be seen in these photographs that the retreat of the coastline has resulted in the loss of a number of the smaller gullies, and large portions of some of the medium sized gullies, for example at C and E. It is obvious from these photographs that gully initiation or extension is not in keeping with the rate of coastline retreat. If this much of the gullies can be lost in forty-odd years, it poses the questions of how much of the gullies has been eroded and for how long these processes have been occurring. These questions will be addressed in Chapter Five.

4.4.2 Field Case Studies

Plate 4.4, taken from the air, illustrates the two types of gully cross sections (U and V). The gully on the left of the photograph, although only a portion of it is visible, is in keeping with a U shaped gully. There is some resemblance of a channel along the bottom that would flow during rain events. The two gullies on the right of the photograph are V shape gullies. Due to their small size and transient nature, these gullies cannot be mapped on the 1:25000 maps. This is where oblique photographs prove to be invaluable. It is possible to see from Plates 4.4 and 4.5 that many of the small, V shaped gullies that have been identified in Tables 4.1 and 4.2 are in fact associated with cliff retreat. As has been mentioned in

Chapter Two, with cliff retreat of approximately 0.5 to 1m/yr, these features will quickly be obliterated, possibly only to extend and be removed again with the eroding cliff, unless they extend at a similar rate as the cliff is retreating. Plate 4.6 is an example of an actual V shaped gully. Notice the slumped material at the mouth of the gully as the near-vertical sides of the gully collapse.

Plates 4.7 and 4.8 are the same gullies viewed from different angles. These gullies are in the field area and are numbered 285 and 284 in Figure 4.1 (284 being the larger gully on the right of the photograph in plate 4.7). Plate 4.9 is the same gully as on the left in Plate 4.7 (number 285). Plate 4.9 is looking up towards the head standing near the mouth of the gully. Note the accumulated rubbish at the head of this gully. It is common to find large amounts of rubbish being deposited within the gullies along the length of the coast. Plate 1.2 is also in the study area (number 286). This is characteristically a V shaped gully with slumping sidewalls. The near surface walls are vertical with the material below being unstable.

Some of the gullies have cut their way right down to be accordant with the level of the present beach. Others seem to be 'hanging' in the cliff face. Examples of hanging gullies can be seen in Plate 4.5 and down-cut gullies in Plate 4.8. Interestingly, no gullies have floors below the level of the present beach. The implications of these different gullies will be discussed in Chapter Five.

Plate 4.4: U and V shape gullies. Note the slumped material within the V shape gullies.

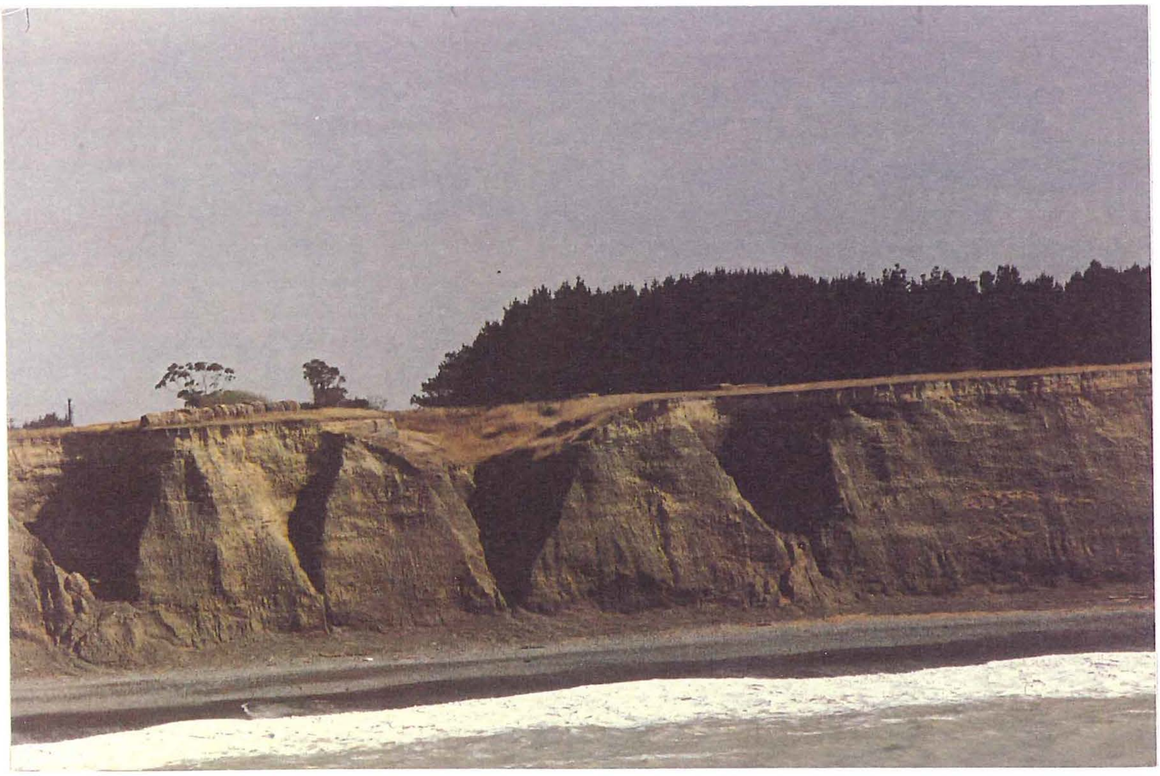

Plate 4.5: V shape gullies. The second gully from the left is a feature of cliff retreat.

Plate 4.6: An actual V shape gully.

Plate 4.7: Gully numbers 284 and 285

Plate 4.8: Gullies 284 and 285 again. Note the rubbish in the left gully.

Plate 4.9: Gully number 285. Gullies being used as rubbish dumps are common.

Plate 4.10: Evidence of piping exiting unconsolidated cliffs.

Plate 4.11: Water seeping out at the base of the cliff. Notice at the marker, water exiting here also.

The field area consists mainly of grass pasture (as can be seen in Plates 4.7 and 4.8). There is evidence that at times some of the area is used to run cattle, although during the field period, there were no cattle present. In one area there was a swamp-like pond present approximately 25 to 30m from the land margin. This was in the vicinity of gully number 286 (Plate 1.2). Situated in the cliff face immediately in front of this 'swamp' area were a number of pipes (Plate 4.10). Because of the unconsolidated nature of the cliffs, it was not possible to examine these carefully, although it was observed that there was a trail of fine sediment exiting the pipes. It could be concluded from this, that piping is a modern feature of the landscape in this area. Water seeping out of the cliff face can be seen in Plate 4.11. Although not large amounts of water, the actual presence of water seeping from the cliffs may be of great importance. As mentioned in Chapter Three, seepage erosion has the potential to initiate gully erosion. The implications that piping and seepage erosion have on the development of the gullies will be addressed in Chapter Five.

The data obtained through survey techniques in the field were used in a graphic package called 'Surfer'. This not only allows for a contour map to be produced, but also a 3-D image of the gully. Figure 4.5 shows the Surfer surface and contour plots for gully number 286. Note on the surface plot the near vertical sides, grading into a sloping surface to form a V shaped bottom surface. Referring to Plate 1.2, it can be seen that the sloping surface is an accumulated talus slope. The contour map reflects this with closely spaced contour lines indicating a steep surface (contour intervals are 0.5m). As can be seen in Plate 1.2, gully number 286 has a stream running down the middle. This gully is used as an outlet for artificial irrigation. It is common for gullies in the study area to be used as outlets for irrigation, as mentioned in 2.6.2, large gullies in the Longbeach area were used to drain the land at the end of last century. Figure 4.6 shows the slope of gully number 286 along the bottom channel (following the stream or thalweg). After an initial drop, the slope levels off, ponding slightly before dropping off towards the level of the beach.

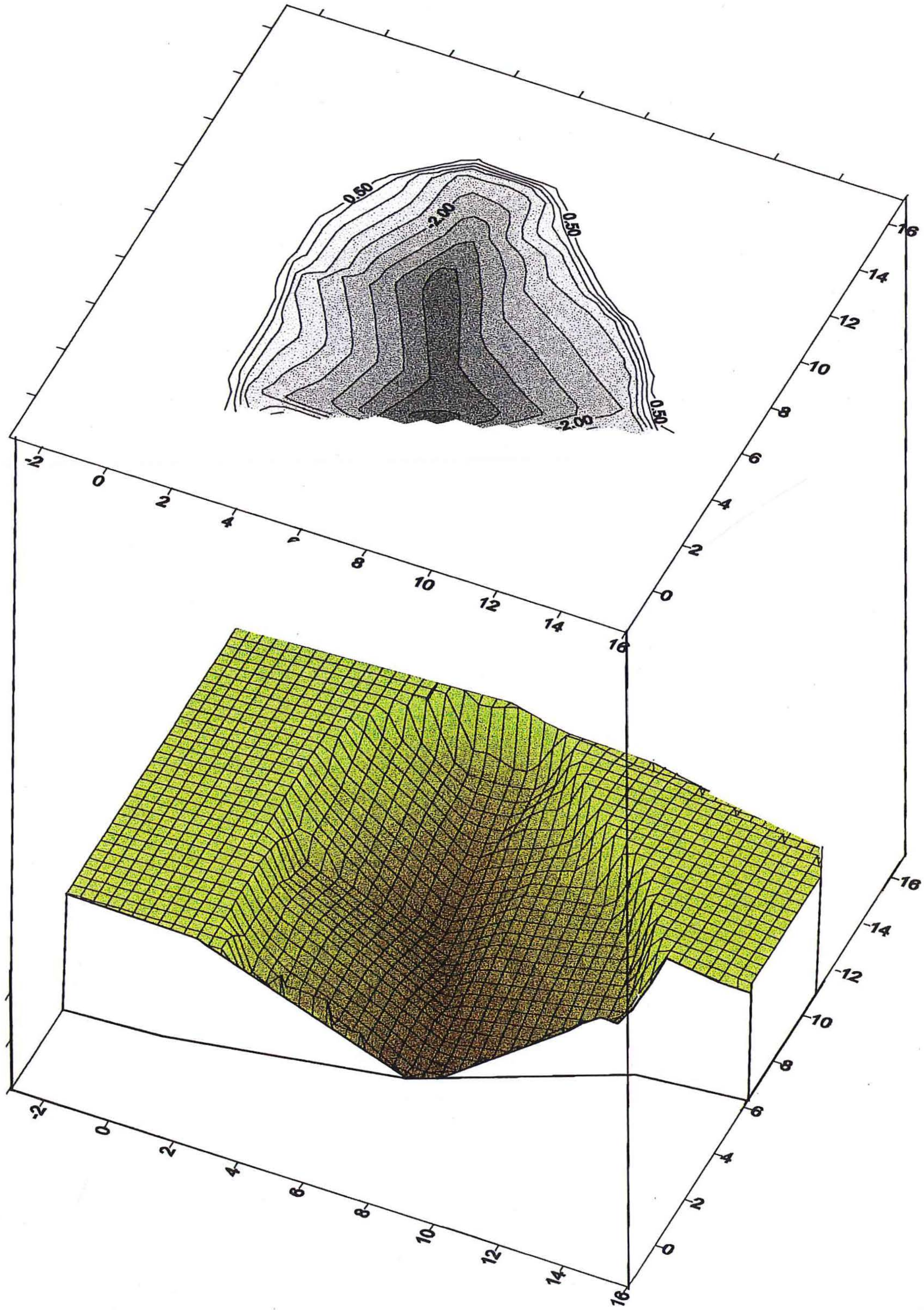

Figure 4.5: 'Surfer' surface and contour plot for gully number 286. Units are in meters.

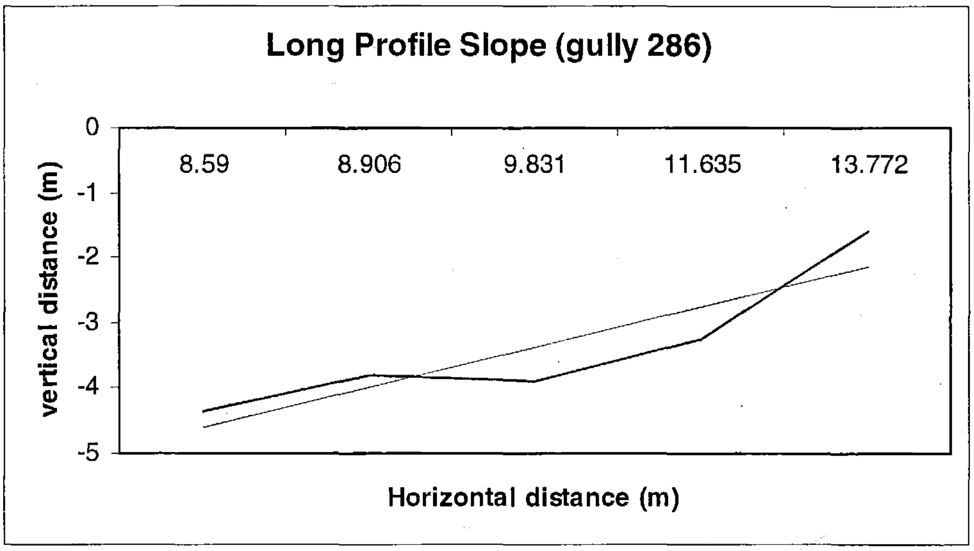

Figure 4.6: Channel slope; gully 286

Figure 4.7 is a Surfer surface and contour plot of gully 285. This gully has moderately sloping sides, tending towards a U shape bottom channel. Predominantly vegetated, the gully walls seem to be stable with no slumping occurring. Erosion occurs only at the upper edges of the side slopes. The main channel is seen to split into two heads, both of approximately the same size.

Figure 4.8, the Surfer surface and contour plots for gully 284, indicate the moderately steep sidewalls and U shape bottom channel. Note on the contour plot for this gully, the marker in approximately the centre of the plot. There, the channel rises where a 'bridge' partitions the gully into two areas. In Plate 4.8, this looks natural, but on the ground, it is obviously artificial. The purpose and date of this feature is unknown. Figure 4.9 is the channel long profile for gully number 283 indicating a channel slope of approximately 10m vertical distance for every 1km horizontal. The estimated slope of the Canterbury Plains in this area is 10m per 1.8km.

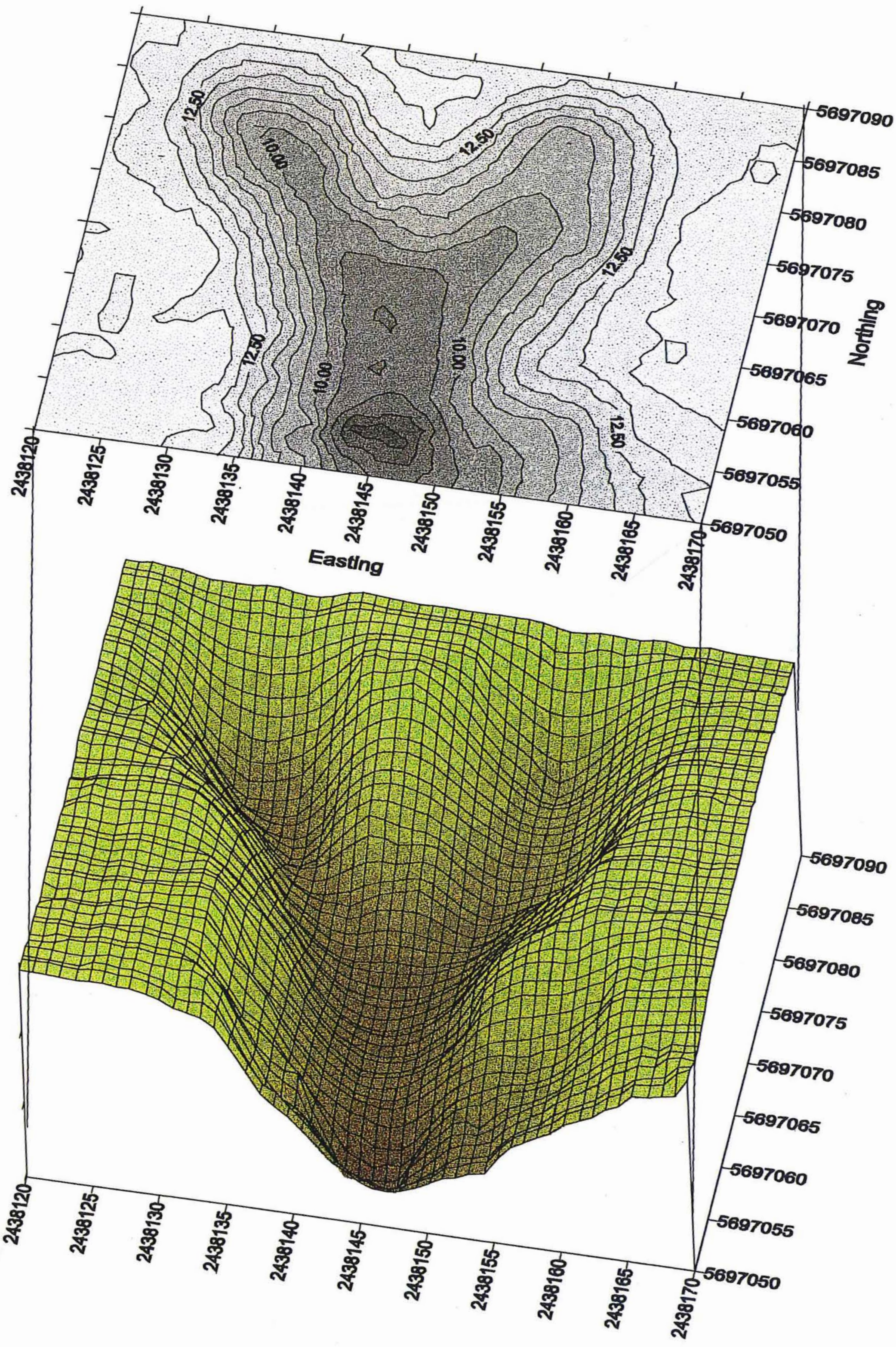

Figure 4.7: 'Surfer' surface and contour plot for gully number 285.

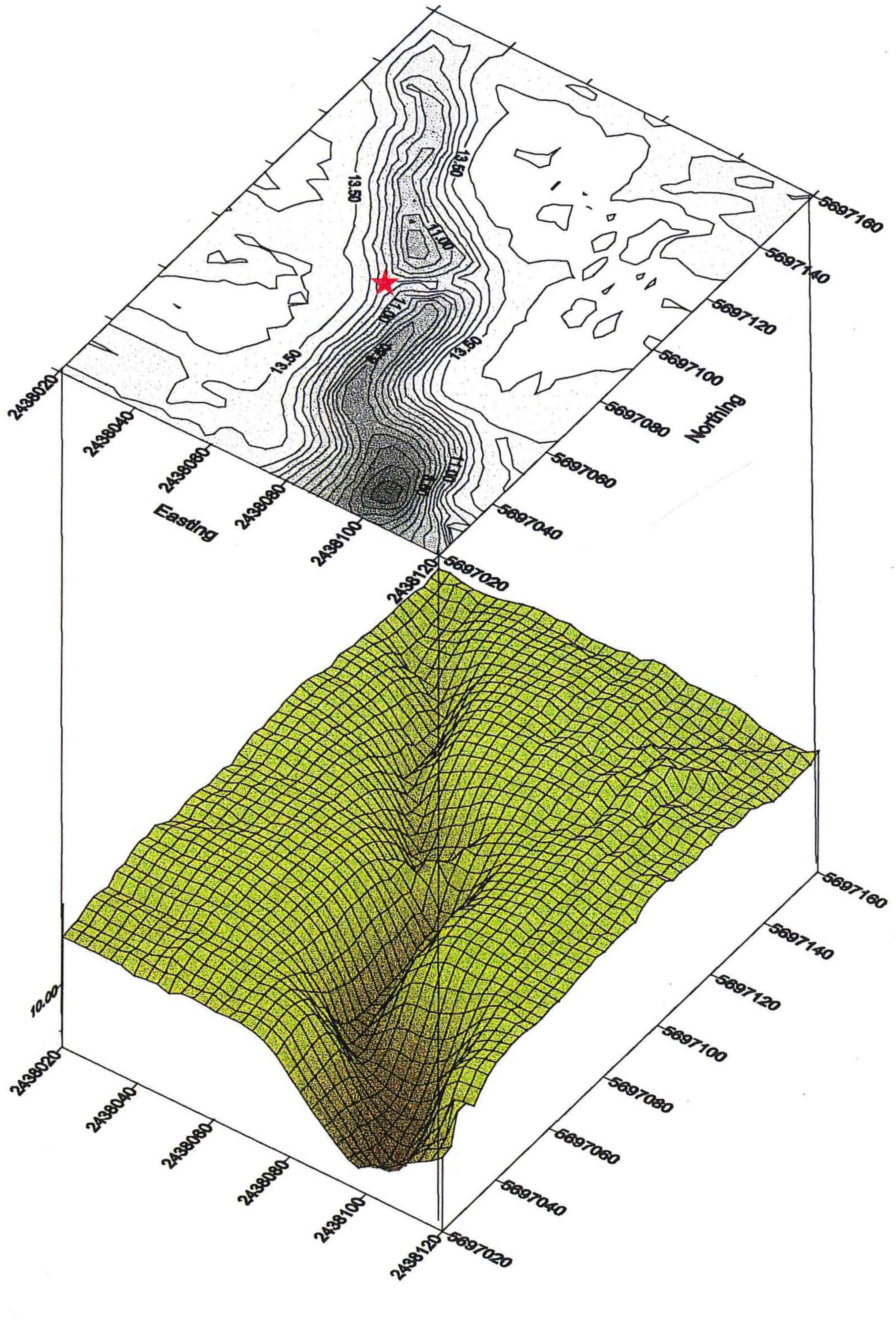

Figure 4.8: 'Surfer' surface and contour plot for gully number 284.

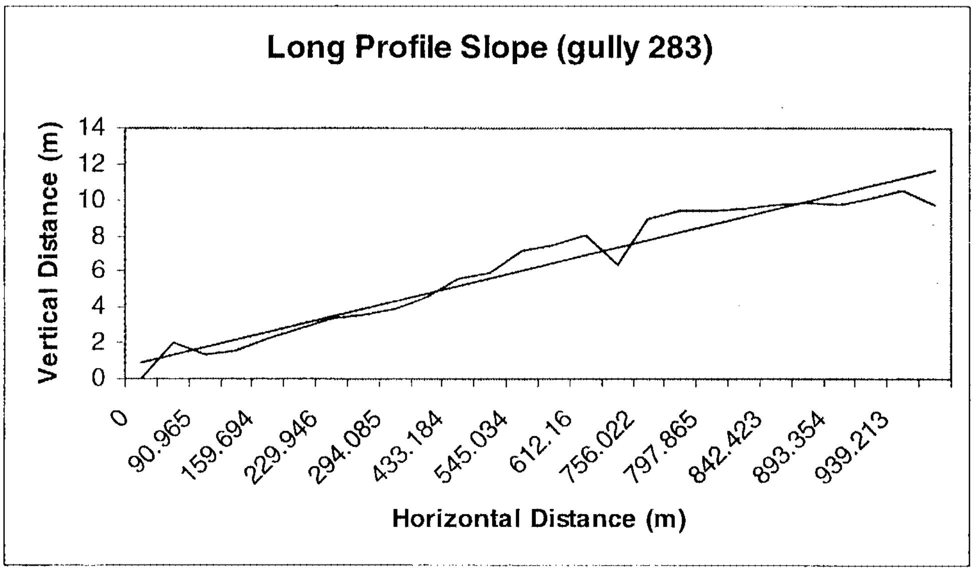

Figure 4.9: Channel slope; gully 283

4.5 Summary

This chapter has presented the methods used in this research including geomorphic mapping, aerial photograph manipulation and interpretation, surveying and observation. Following the methodology section, an introduction to the data was presented. All aspects addressed in this chapter are to be discussed in the following chapter, tying together information obtained throughout the previous chapters. Chapter Five will concentrate on determining the type of gullies being examined, their age and origin.

Chapter Five

Discussion

5.1 Results

This chapter reviews the material presented thus far and discusses the results introduced in Chapter Four. The implications introduced in the previous chapter are revisited here and are combined with pertinent information from Chapters Two and Three. Finally, this chapter will introduce possible scenarios for the origin of the gullies.

5.1.1 Statistical Analysis

The results and plates illustrated in Chapter Four give an indication of the landforms in question. Their approximate number, distribution and parameters have been introduced but the importance of such aspects is yet to be discussed.

The 298 gullies examined stereoscopically and reported in Table 4.2 were nearly evenly split between the U and V shape categories. As stated in 4.4.2, many of the V shape gullies identified in Table 4.2 are, possibly, aspects of cliff erosion rather than actual gullies. Because these features are formed and obliterated with the eroding coastline, many are too small to be seen on the aerial photographs. This is evident when viewing Plates 4.4 and 4.5.

With an estimated 20m having been eroded from the cliff face (according to the average of 0.5m/yr) since this time (1952), the erosional features observed in these photographs have been removed. They have though been replaced by more recent erosional features, continuing the cycle of cliff retreat. Other V shape gullies are associated with artificial irrigation outlets. As can be seen in Plate 1.2, surface water flowing off the area has the potential to erode material from the cliff face, producing modern erosional features in the landscape. In situations such as this, the erosional process is operating from the surface downwards, eroding the upper layers until a more stable layer is met. The stable layer may be a hardpan layer or a more consolidated stratigraphic layer. In these erosional features, there would be no vegetation as erosion is a continuing process, working in a lateral direction to produce near vertical walls and a V shape channel. Although operating under different processes, cliff retreat results in similar landforms. As shown in Chapter Three, through equifinality, different processes may result in a similar landform.

As can be seen in Table 4.2, nearly 70% of the gullies are first order channels. The Chi^2 tests from Chapter Four reveal that a substantially greater than expected number of V shape gullies are first order and not vegetated. The high number of first order, non-vegetated gullies would be expected given the unconsolidated nature of the coastal cliffs in this region. Antithetically, the U shape gullies tend to exhibit more branching with 57% of U shape gullies being above first order. Also, 97% of U shape gullies are vegetated compared with only 13% of V shape gullies.

As can be seen in Table 4.3, 80% of the gullies are 10mm (scale 1:16,000 where 10mm is $\approx$160m on the ground) or less in length on the 1952 photographs and the majority of these are V shape. In fact, all V shape gullies (except one) are less than 10mm in length and more U shape gullies than expected are greater than 10mm. It could be that as the gullies extend in length, they also extend laterally, hence the longer gullies being U shape and vegetated. Figure 5.1 has grouped the gullies in a logarithmic scale according to the length of the gullies. It is possible to see groupings length brackets implying that there are indeed, a number of groupings according to size.

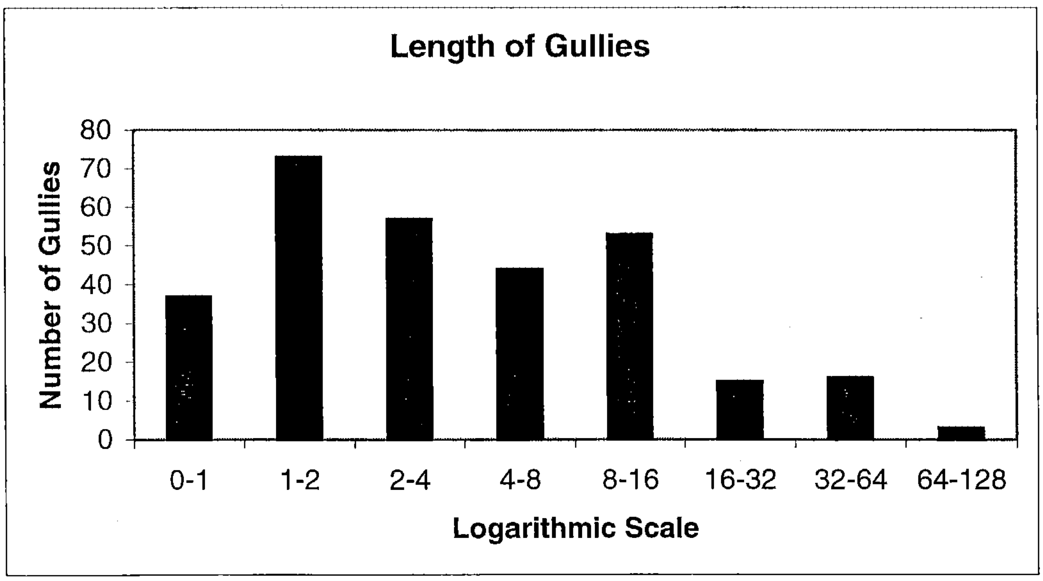

Figure 5.1: Gullies grouped according to length (logarithmic scale).

As mentioned in the previous chapter, there is a preference for all gullies to be perpendicular to the present coastline. Extremes range from 50° to 140° with only three gullies outside these limits. Figure 4.2 shows diagrammatically the representation of gully orientation in relation to the coastline. The exception to the perpendicular bias is a tendency for V shape gullies to be at 0-79° and U shape gullies to be above 100° (Table 4.5). A theory tested was that gullies on the south of the rivers would be in the order of 101-170° and on the north would be 0-79° as water would flow into the rivers. This however proved not to be the case and there was no significant spatial clustering of orientation. It is not possible to formulate an hypothesis based on this inconclusive evidence. It remains an interesting feature of the data, that although a majority of the gullies are oriented at an angle no greater than 10° from the perpendicular, no V shape gullies were beyond the 100° angle and no U shape gullies were less than the 80° angle. This data can be seen in Table 4.5.

Based on the slope data for gully number 283, it is possible to formulate an hypothesis about the length at which the gully may have extended in the past. Given that the slope of the Plains in this area is 10m: 1.8km, the average rate of cliff retreat is in the order of 0.5m/yr, that the height of the cliffs in the area is approximately 12m, and the slope of the gully is approximately 10m: 1km, the amount of erosion can be estimated. Taking into account the vertical distance from the cliff base to mean water level is approximately 8m, the distance required for the gully floor to reach a base level of sea level would be 400m. The time required to erode this distance is 800 years. This is however only a very rough indication of the possible extension of the gullies with an extended coastline. This has been based on the slope of only one gully and therefore it is not possible to categorically assume this data is correct for all gullies. This does though give an indication of the order in which initiation was possible.

5.1.2 Case Studies

Plate 4.1 depicts an overlay of 1952 and 1996 aerial photographs for the area around gully number 283. These photos provide ideal examples of the errors occurring in vertical photography. The center of the image matches, but towards the right and left there is some distortion resulting in an uneven overlay. As suggested in Chapter Four, this can be overcome by using only the center of the photographs. Unfortunately, in this instance, this method of photographic manipulation has proved to be less than ideal. It is difficult to determine any minor changes that may have occurred as the layering obscures information below. It is evident that there has been substantial cliff erosion as can be seen at the locations indicated by arrows. However, this is the only conclusion that can be formulated from this method.

Another method of comparing two different years is by positioning the images side by side rather than on an overlay. In this way, there is no possibility of obscuring information beneath another image. The same gully has been displayed in this manner in Plate 4.2. Taking particular note of points A, B and C, it is clear that at least in the period between these two photographs being taken, there has been no extension of the gully. Again, the main changes over this period are a retreat of the coastline and an increase in vegetation cover.

This same method of manipulation has been used in Plate 4.3, comparing the gullies around the area of gully number 200. It is apparent from these photographs that there has been no significant extension of the gullies. Cliff retreat has been a major part of development in the area as can be seen at points C and E. A substantial portion of the smaller gullies has been removed with the eroding coastline. It is obvious that extension of the gullies is not in keeping with the rate of cliff retreat. The only other development has been an increase in vegetation cover as can be seen at points A, B and D. This increase in vegetation supports the theory that the gullies are relict features of the landscape as vegetation would not develop and stabilise on an eroding surface.

The information obtained from this inspection of the aerial photographs has lead to the theory that there are at least two distinctly different types of gullies. Plates 1.2 and 1.3 give examples of two extremes in gullying within this location. Another category could be added to these groups; those of an 'intermediate' state, which can be seen in Plate 1.4. It is clear that at least the small gullies (Plate 1.2) are of a different age than the others, and possibly produced by a different mode of formation. It is also possible that the intermediate gullies are of another time frame, or, that they have not developed to their full potential.

The three surface and contour plots introduced in Chapter Four each illustrate the different sized gullies mentioned. Figure 4.5 represents a small gully. The V shape bottom is indicative of a recent feature of the landscape with talus slopes occurring as the sidewall slump. Figure 4.7 is an example of an intermediate gully. These types of gullies look as though their development has been cut off in mid process. The bottom channel is generally tending towards a slight U shape, whilst the sidewalls are moderately sloping but vegetated.

Alternatively, Figure 4.8 is depicting a larger, established gully. The bottom channel is a well-defined U shape with gently sloping sidewalls. The resultant head is gently sloping with no clear-cut break in slope. The large gullies are usually accordant with the present beach level while some of the intermediate and small gullies 'hang' in the cliff face. This could be another indication of differing ages. It has been suggested that the smaller V shape gullies are of a present age and that they can regenerate and migrate with the eroding coastline. It could be that the intermediate gullies at some point were of this same nature. Although relict now, they may have evolved from a more recent event than that of the larger gullies.

5.2 Timeframes

5.2.1 Environmental Changes Revisited

It has been estimated that clearance of the forest in this area occurred around 600 years BP and an increase in cooler, wetter and windier conditions around 7500 years BP. From 7,000 to 5,000 sea level was stabilising and reached its present level, some 130m higher, around 5,000 years BP (Kirk, 1994). Cliff erosion along this stretch of coastline is averaged at 0.5 to 1m/yr and has been occurring for thousands of years. The study area, in geologically recent times, was comprised of a number of isolated swamplands until European settlers drained this water in order to accommodate their farming practices.

5.2.2 A Condensed Timeframe

Referring to the time frame set out in Chapter Two for which the gullies could have developed, it would have been between 150 to 20,000 years from the present. The presence of the gullies was documented by early European settlers and displayed on early maps of the time such as the 'Black Maps'. At the other extreme, sea level had attained its present level by 5,000 years BP, where, previously a lower sea level by

130m meant that the eastward margin of the Plains was up to 50km further east (Kirk *et. al*, 1977). This occurred around 20,000 years BP before world sea levels began to rise.

There is no record of whether the larger gullies were relict features of the landscape at the time of European settlement or whether they were still forming. It is known as fact that they were present during early European settlement. If the removal of vegetation and an increase in precipitable moisture were available at the same time, this could lead to an ideal explanation for the development of the gullies. However, because these events do not match in scales of time, another upper limit needs to be revised. It does not seem probable that the gullies could have developed and survived a period prior to deforestation, nor do they appear to be features capable of withstanding the elements for 20,000 years. Based on this, it would seem viable to put the upper limit for initiation around the period of deforestation, some 600 to 500 years BP.

5.2.3 Sources of Information

A valuable source of information pertaining to the fluvial and geomorphic history of the Canterbury Plains is revealed in many of the early maps produced near the end of last century. Reputable names such as Von Haast, Jollie and Torlesse are associated with such maps. Figures 5.2 to 5.5 are examples of such early maps. Figure 5.2 was produced in 1849 and clearly shows that what is now the Hinds River, reached the coast. Also present on this map is another river between the Ashburton and Rakaia Rivers which is not present today. Figure 5.3, from 1855 exhibits the same features with the extra river being referred to as Wanganui or Wynn River. By 1866 (Figure 5.4), the Wynn River was not being represented on the maps and the Hinds River no longer extended to the coast. Figure 5.5 (1867) clearly shows that the Hinds River is disjointed and has no outlet to the sea. It was not long after this that John Grigg started the drainage of the swamp at Longbeach and extended the path of the Hinds River to reach the sea.

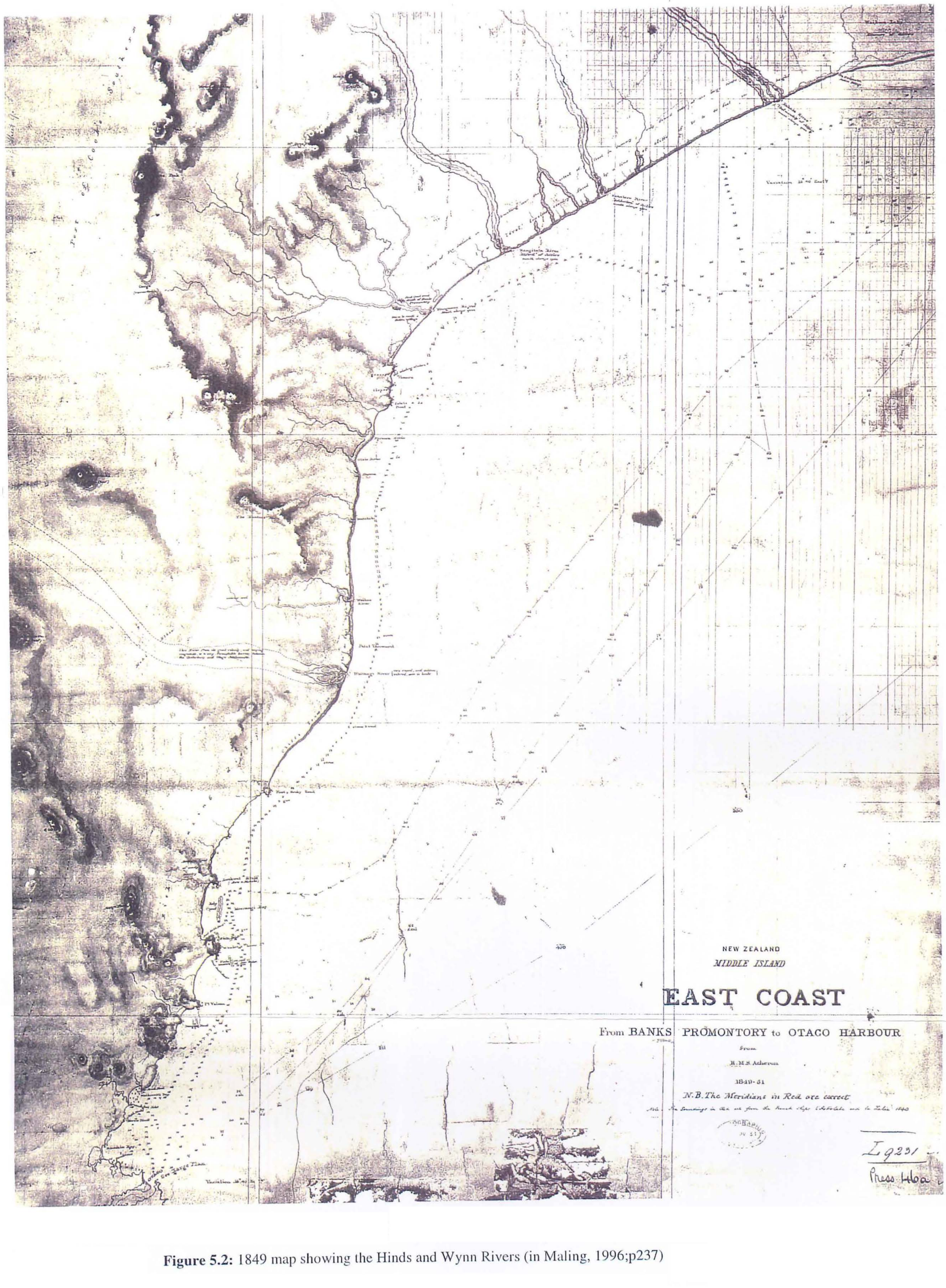

Figure 5.2: 1849 map showing the Hinds and Wynn Rivers (in Maling, 1996;p237)

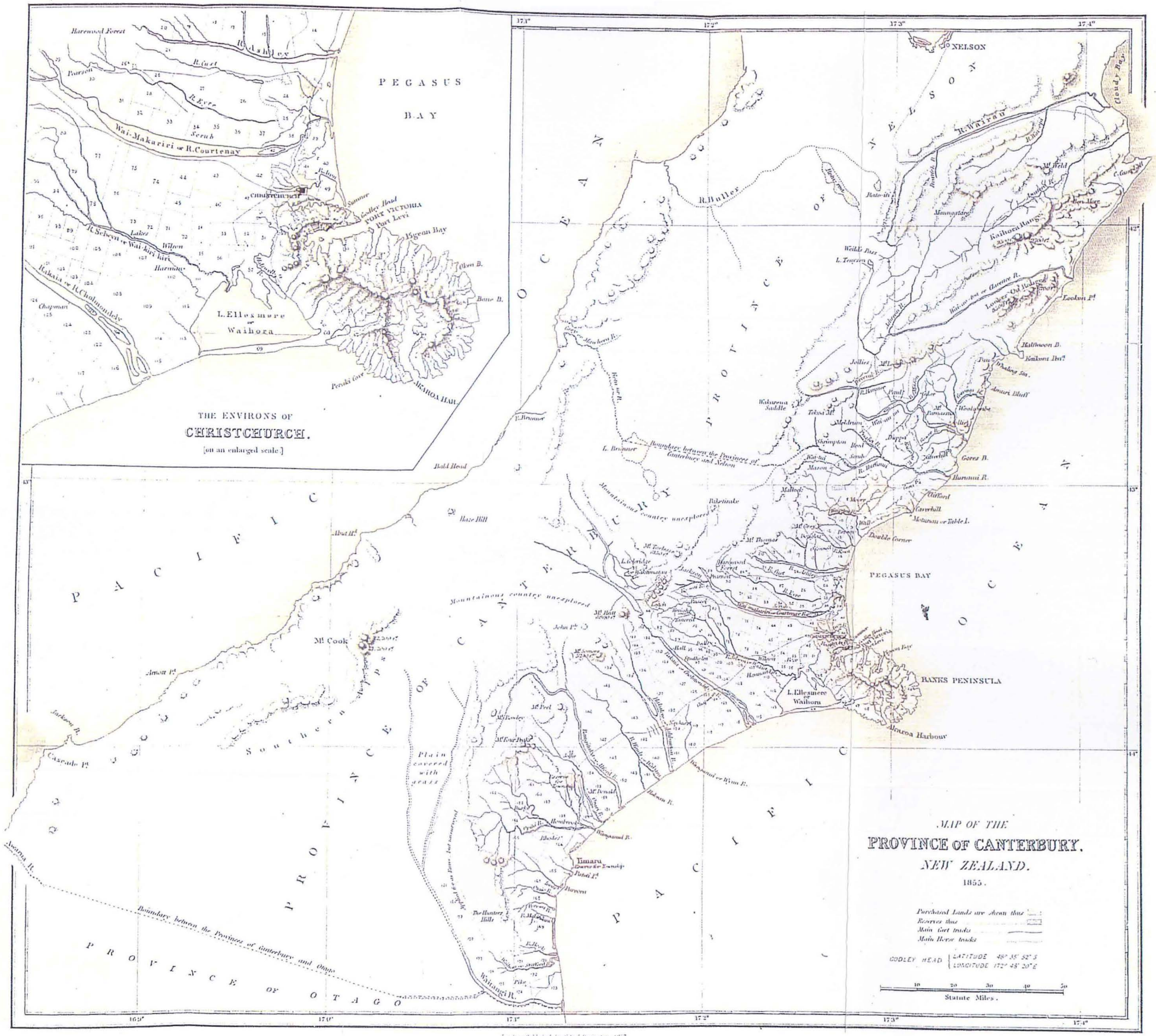

Figure 5.3: 1855 map showing the Hinds and Wynn Rivers (in Maling, 1996; p234)

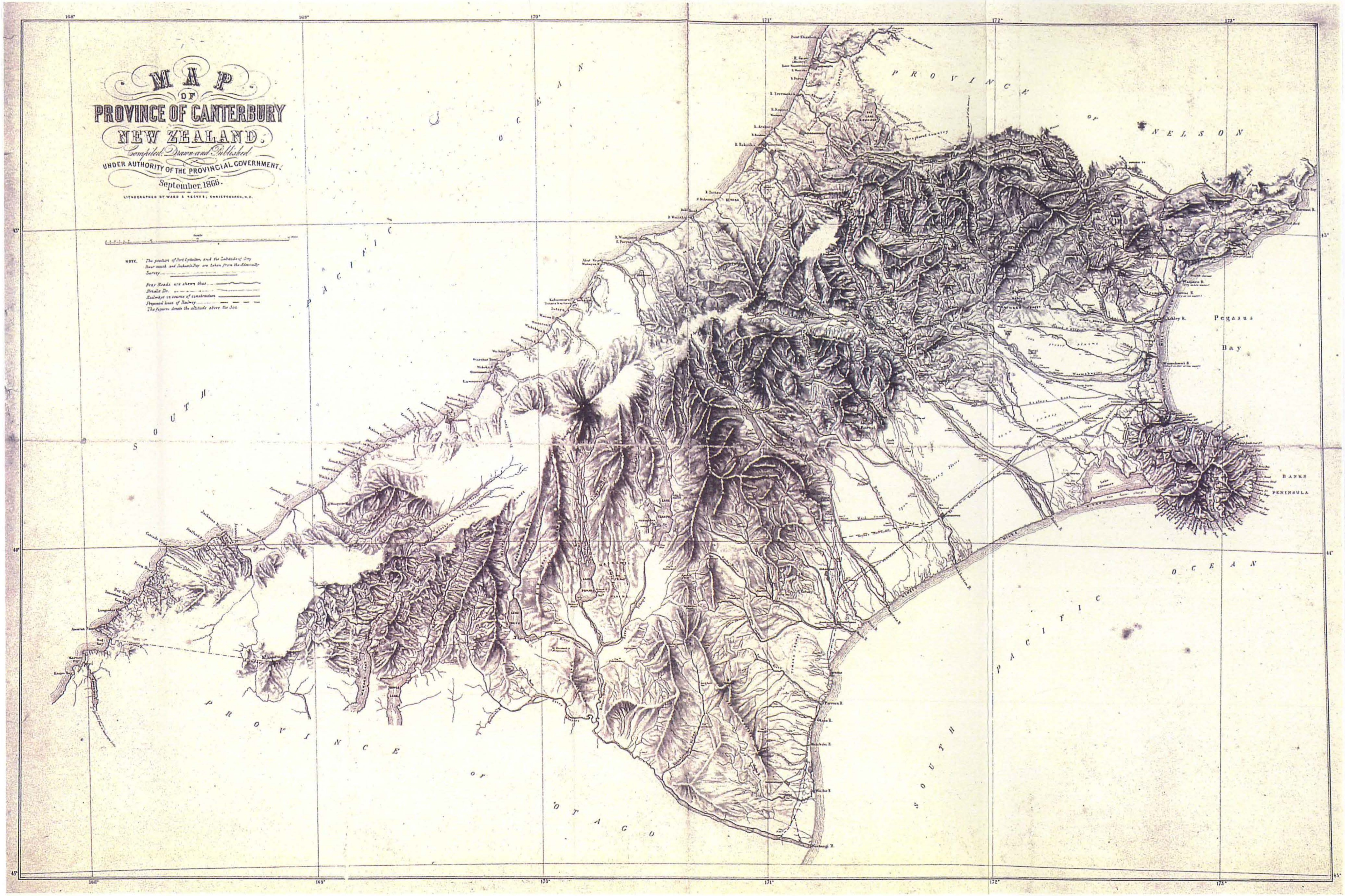

Figure 5.4: 1866 map showing break in the Hinds River and no Wynn River (in Maling; 1996; p251)

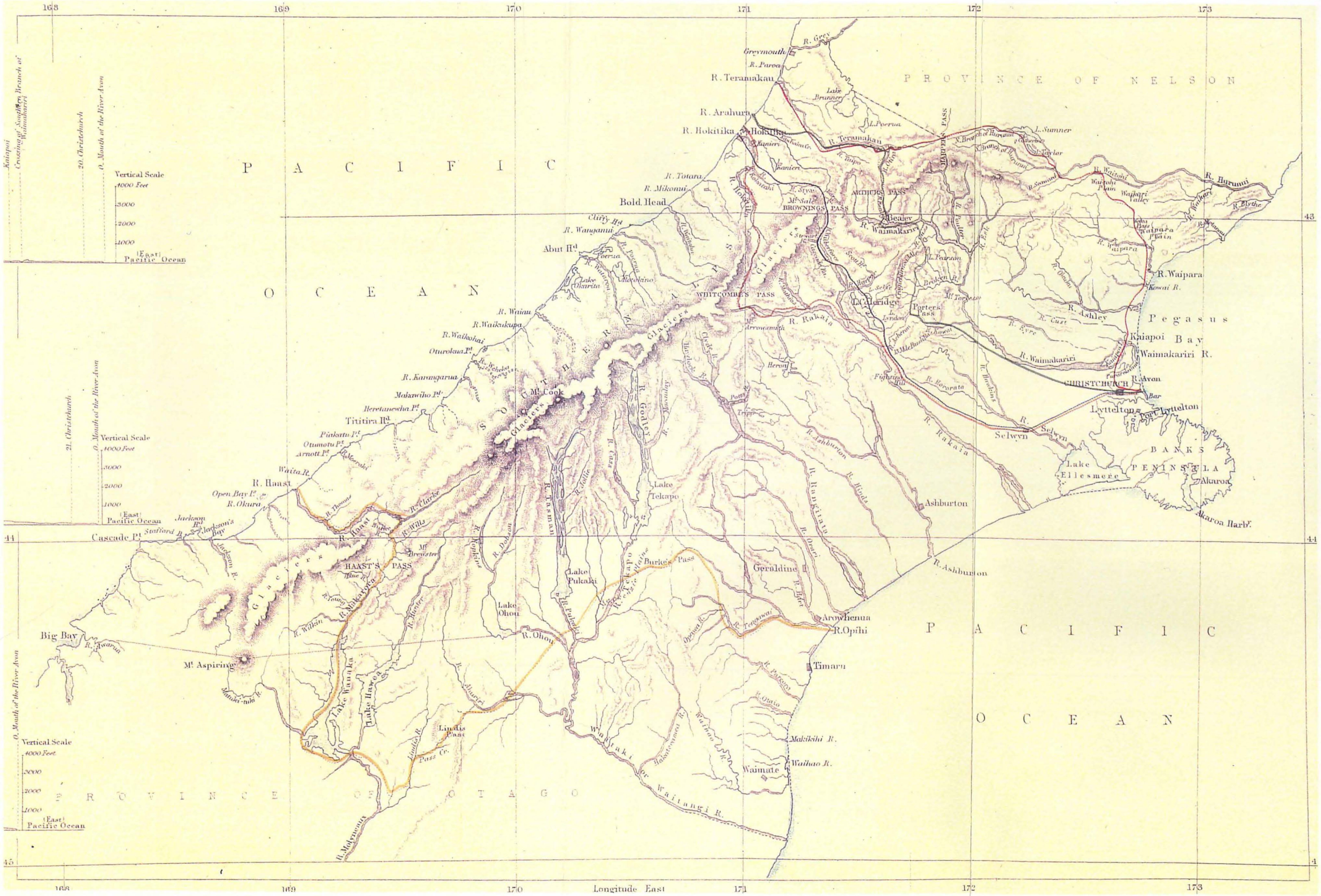

Figure 5.5: 1867 map showing a break in the Hinds River and no Wynn River (in Maling, 1996; p247)

It would seem from these maps that there was a change in fluvial activity at some time near the end of the last century. It is possible that irrigation and the many artesian wells sunk on the Canterbury Plains may have resulted in a reduction of water in the area. Other possibilities for the change in fluvial activity are localised climatic variations. It is well know that Canterbury fluctuates considerably between climatic events, often experiencing drought conditions. Flow conditions may also have changed over this period with increased through-flow as opposed to subsurface flow. However, caution needs to be practiced when examining these old maps. The conditions under which the maps were surveyed for, or cartographically represented, will greatly impact on the way in which they are presented. There is less than 20 years between the maps in question, geologically a very short time in which a change in fluvial activity could have occurred.

5.3 Gully Types

Chapter Three introduced the wider literature on gully formation and different types of gullying. With the information obtained in Chapter Four, it is possible to speculate as to where the gullies in the study area fit into this literature. The short, V shape, unvegetated gullies correspond to Glock's (1931) stage of *initiation* or 'birth' of the drainage system. The small and intermediate gullies under Ireland *et. al's* classification system would be a combination of Bulbous and Dendritic gullies. The larger, predominantly vegetated U shape gullies correspond to Glock's (1931) *elongation* and *elaboration* stages. Under Ireland *et. al's* classification, these larger gullies would also encompass the Linear grouping as well as the two mentioned above. Interpretation of Imeson and Kwaad's (1980) conditions fall between types 2, 3 and 4 in relation to position in the landscape, principal source of runoff and materials in which gully is developing.

5.3.1 Dongas

The local use of the word Donga in reference to these gullies, as discussed in Chapter One, deserves special mention. As far as the author is aware, donga is a colloquial term for gullies, derived from a Zulu word, and used extensively in southern Africa (Frankel and Scogings, 1960). The term donga there is used widely to describe gullies in a variety of settings ranging from sandy deserts to coastal regions and in a number of positions within the landscape (King and Fair, 1944; Watson *et. al*, 1984; Watson *et. al*, 1986; Yaalon, 1986). There seems to be no clear-cut definition of a Donga other than that they are erosional features of the southern African landscape. As previously mentioned, many authors have used the term Donga in reference to these gullies but give no reference as to where the name came from. It would seem inappropriate therefore to use this term in association with the gullies of the Canterbury Bight.

5.3.2 Processes of Gully Formation

It is difficult to try to determine the processes that produced these landforms. The difficulty lies in that what is being observed is the remnant of a previous process. If the features were depositional, there would be some indication of the process that developed it. Unfortunately, when dealing with erosional features, many of the indicators have also been eroded, and we can therefore only speculate as to the events that may have occurred. In this respect, it is necessary to hypothesise based upon previous literature on a related subject, and look for any existing indicators within the field.

Burkard and Kostaschuk (1995, 1997) describe a similar gullying system occurring around Lake Huron, Ontario. Gully initiation in their study area coincided with deforestation and settlement within the area. An increase in drainage and irrigation upon the cleared surface resulted in the initiation of gullying. Revegetation in the area resulted in a decrease in erosional activity.

Gomez and Mullen (1992) conducted laboratory experiments that concluded that sapping produced a gully network separated by ridges of uneroded material. Their findings paralleled those postulated by Glock (1931) in regards to the three steps of gully growth. *Initiation* was characterised by the headward growth of a single trunk stream. *Extension* saw the growth of tributary channels and *abstraction*, the lateral expansion of the network. Figure 5.6 is a diagrammatic indication of their findings. These stages of development can be correlated with growth and extension of the gullies within the study area. The early stages of growth can be compared with intermediate gullies. The latter stages could be compared with the larger gullies in the study area.

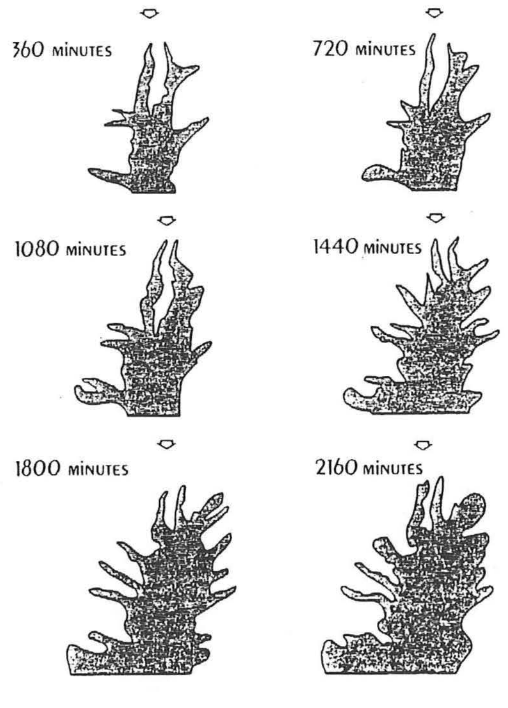

Figure 5.6: Diagrammatic indication of sapped drainage network (from Gomez and Mullen, 1992)

Baker *et. al* (1990) obtained similar results in their laboratory experiments as those produced by Gomez and Mullen. In the Baker *et. al* (1990) experiments, it was concluded that rilling is also an important factor in gully growth as can be seen in Figure 5.7. Comparing this with the 1952 photograph in Plate 4.2, it is not possible to observe indicators that rilling is a process occurring within gully growth in this area. As no evidence was observed on the ground of rilling occurring, it can be concluded that this is not an important factor in the study area.

Water seeping from within the cliff face as can be seen in Plate 4.11 is an important indicator of a subsurface water source. Piping exiting the cliff face also indicates that such water is available for erosion. It is important to remember the historical extent of swampland around the area of the east coast coastal region. Evidence of piping occurred around an isolated area of swamp referred to in Chapter Four reinforces the theory that water being removed from the swamp may initiate gully development. Only limited piping was observed over the study period, possibly due to the severe drought that has afflicted Canterbury over the study period. As piping commonly initiates in rodent burrows or decaying root channels, it is plausible that gullying was initiated around the period of deforestation some 500 to 600 years BP. The removal of the forest cover would not only have provided an outlet for which piping could occur; it would have also left the surface bare for surface erosion.

Figure 5.7: Gully growth due to rilling (from Baker *et. al*, 1990).

5.4 Possible Scenarios

5.4.1 Time Frame

Given the data available, it is not possible without reserve to formulate an hypothesis about the age and origin of the gullies. Based on the information available, it is possible to express a number of conceivable scenarios. The gullies are too modern to be considered as being anywhere near 20,000 years old; the age of the sea level before it rose to its present level. It is more likely that the gullies were formed around the time of deforestation in the area, that being about 500-600 years BP. As it is known that the gullies existed at least in 1855, it is postulated that the gullies were initiated within this time frame, more likely towards the older age bracket. Having said that, it has been presumed that there are at least two different ages for the gullies. It can be said without doubt that the smaller gullies are of a modern age, many of which are still forming. The difficulty lies with the intermediate and large gullies. There are at least two options in regards to the different sizes of these gullies. One is that the intermediate gullies are actually the fingertip remains of branches off the main, large gullies. Another option is that the intermediate gullies are erosional landforms in their own right. In this respect, the intermediate gullies either initiated at a different time to the larger gullies and in a smaller event, or, they occurred at the same time as the larger gullies but did not develop to the extent as the larger gullies.

5.4.2 Processes

Through examining the aerial photographs, it is evident that there is a distinct difference between the intermediate and large gullies. Through inspection of the old maps (Figures 5.2-5.5), it could be concluded that there was, around the period of 1850, an event that resulted in an increased amount of water being present in this study area.

How this water resulted in the initiation of the gullies is the next area of speculation. As has already been mentioned, there is difficulty in determining a theory based on erosional formations as the indicators have been removed with the process that produced the landform. A question arises as to whether the gullies were formed in a single, large event, or whether erosion occurred over a longer period. It seems unlikely, given the size of some of the larger gullies, that they could have been produced in one event. It is more likely, that after their initial formation, development continued over a period of time.

Schumm and Phillips (1986) attribute the formation of the larger gullies to overland flow from swampland, later modified by seepage-induced sapping. As mentioned in Chapter Two, there is no evidence of the swamp extending north of the Ashburton River at least during European time. However, this is not to say that at some time there has not been swamp in this area. They ascribe the formation of the smaller gullies to groundwater sapping. In relation to the formation of the smaller gullies, it does seem likely that groundwater sapping could initiate the removal of sediment from beneath the surface. Once this has been started, surface irregularities would result in the continued erosion of sediment at these points due to water being channelled into these areas. In regards to the larger gullies, subsurface initiation is a favoured option. As has been shown in Chapter Three, piping occurs along lines of weak, fine material. It is known that this type of structure is present within the make-up of the Canterbury Plains, and there is observed evidence of this process occurring in an area of coastal swamp. Water draining from the areas of swamp through pipes or seepage to the sea would carry with it amounts of sediment. Once sediment has been removed, the pipes may collapse, resulting in an irregularity to which water may be drawn through sapping or surface processes. A new, steep hydraulic gradient produced by the collapse of the pipe would also draw water into the new channel. Since pipes may be up to metres in diameter (in fine sediment), a substantial amount of sediment may be initially removed as the first step of the process of erosion. Although piping has been observed in the study area, it is not at a scale in keeping with metres in diameter.

It would seem more likely that surface processes played a large part in the initiation of the largest gullies as suggested by Schumm and Phillips (1986). By magnitude alone, piping would not have the capacity to initiate such large-scale features, particularly within a mixed sand and gravel matrix, although this process may be prevalent in some of the smaller gullies.

Chapter Six

Conclusions

6.1 Objectives Recalled

This thesis has investigated a number of erosional landforms found along the cliffed coastal margin of the Canterbury Bight, New Zealand. The landforms studied are gully features scoured into the Canterbury Plains.

This thesis set out to achieve two main aims in order to study the gullies. The aims investigated were:

1 Investigate and describe the extent and location of the gullies

2 Examine their form and development in regards to their mode of formation.

6.2 Summary of Major Findings

The extent and location of gullying was examined and it was found that although not exclusively, extensive gullying is situated along a 60km strip between the Rakaia and Rangitata Rivers. An estimated 300 gullies occur in this region with a range of sizes from 10's of metres to an upper limit of 6km in length. There has been found to be at least two different age groups for the gullies, but in reality this number is probably higher.

Three size groups have been identified, those being *small*, *intermediate* and *large*. It is unknown at this stage as to whether the intermediate gullies are features in their own right, or are the remains of fingertip tributaries being eroded by the retreat of the coastline.

A number of scenarios have been suggested for the development and formation of the gullies. It was found that the small gullies are characteristically aspects of cliff retreat and irrigation practices while the larger gullies are now relict features of the landscape, produced by some other process at an earlier date. It is suggested that, although subsurface water is an important part, initiation of the larger gullies can be attributed to surface runoff.

6.3 Suggestions for Future Research

The research presented in this thesis has provided an introduction to a topic that has provided much interest, but which has been lacking in attention. A lot more is known about these gullies than had been previously, although there is a lot of scope for future research to follow on the themes presented here.

Before this subject is taken further, a major issue that will need to be addressed is the issue of access to private land. This has been a significant restriction in this research but is an area that needs to be addressed by the landowners, Federated Farmers, the Department of Conservation and the Ashburton District Council.

Future research needs to concentrate more closely on the time frame for which the larger gullies may have been initiated. This could be obtained through a more thorough investigation into the slopes of the gully channels in relation to the surrounding Plains and carbon dating of material from within the gullies would also aid in this process. In addition, an analysis of the sediment structure comparing areas that has substantial gullying with areas that do not. Unfortunately, this was beyond the realms of this thesis.

Another area for future research would be to estimate the amount of sediment that has been removed from these gullies and put into a much larger system. Sediment from this area is reported to be deposited in the region of Kaitorete Barrier adjacent to Te Waihora, adding a substantial amount to the sediment budget in this area.

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Appendices

Appendix one: vertical aerial photographs.

1952 1:15960 black and white	1996 1:27000 colour
SN 804	SN 12208
2121/48,47,46	313089 BB/45
2122/33,32,31	309141 HH/35
2123/40,39,38	309102 FF/36
2124/35,34,33	309109 GG/37
2125/33,32,31	309009 CC/47
2126/30,29,28	309063 EE/38
2127/23,22	309061 EE/40
2128/21,20,19	309057 DD/45
2129/16,15,14	309055 DD/43
2130/13,12,11	414683 AA/48
2131/9,8,7	414681 AA/50
2132/7,6,5	
2133/4,3,2,	

Appendix 2: Aerial Photograph Investigation (n=318)

number of gullies	length (mm)	angle from coast (degrees)
1	1	90
2	2	65
3	3	90
4	14	125
5	2	140
6	1	90
7	2	70
8	8.5	140
9	11	135
10	1.5	60
11	1	60
12	0.5	80
13	1.5	90
14	6	73
15	8	78
16	1	90
17	7	90
18	3	66
19	5	90
20	4	70
21	4	75
22	15	83
23	16	108
24	14	116
25	3	110
26	11	63
27	3	94
28	1.5	87
29	15	73
30	9	60
31	14	56
32	16	60
33	18	90
34	11	73
35	10	90
36	12	110
37	5	90
38	2	90
39	4	90
40	5	120
41	7	98
42	2	110
43	5	93
44	9	106
45	8	90
46	16	90
47	1	90
48	3	70
49	21	130
50	4	54

51	10	95
52	32	90
53	64	103
54	2	85
55	6	90
56	28	114
57	55	90
58	80	90
59	23	90
60	1.5	90
61	1	80
62	1	90
63	1.5	90
64	1	90
65	1.5	90
66	1	90
67	1	90
68	6	40
69	12	90
70	8	110
71	0.5	90
72	0.5	90
73	37	117
74	1	90
75	5	110
76	1	90
77	1	90
78	1	90
79	10	112
80	4	142
81	12	109
82	1	90
83	1	90
84	42	105
85	1	90
86	1	90
87	3	90
88	22	110
89	10	90
90	6	90
91	1	90
92	8	103
93	14	124
94	5	80
95	1	90
96	48	90
97	2	90
98	2	90
99	0.5	90
100	0.5	90
101	1	90
102	50	120
103	1	45

104	1.5	90
105	4	90
106	5	90
107	44	85
108	2	73
109	3	90
110	2	90
111	1	90
112	36	90
113	12	110
114	1	90
115	1	90
116	1	90
117	1	90
118	51	85
119	13	98
120	1	90
121	2	90
122	68	100
123	1	90
124	1	90
125	50	103
126	3	90
127	1	90
128	1	90
129	1	90
130	24	105
131	1	90
132	0.5	90
133	1	90
134	1	40
135	45	90
136	0.5	65
137	1	80
138	1	90
139	38	108
140	0.5	90
141	0.5	90
142	0.5	90
143	1	90
144	1	90
145	0.5	90
146	9	100
147	6	90
148	1	60
149	4	65
150	11	90
151	11	90
152	65	115
153	1	90
154	3	90
155	10	80

156	16	80
157	38	90
158	3	90
159	144	90
160	6	50
161	22	75
162	1	90
163	224	90
164	3	90
165	2	90
166	1.5	90
167	4	160
168	2	60
169	2	110
170	1	90
171	2	90
172	2	90
173	2	90
174	0.5	90
175	7	90
176	5	60
177	4	55
178	2	90
179	2	90
180	13	90
181	4	90
182	1	90
183	1	90
184	8	74
185	7	80
186	18	90
187	1	90
188	7	90
189	23	103
190	1	90
191	5	90
192	3	90
193	2	70
194	1	90
195	28	95
196	18	85
197	10	90
198	9	90
199	4	90
200	15	90
201	4	90
202	5	90
203	22	90
204	2	90
205	1	90
206	1	90
207	2	90

208	3	90
209	7	40
210	11	90
211	1	90
212	11	90
213	1	90
214	1	90
215	2	90
216	1	40
217	1	90
218	2	90
219	1.5	90
220	1	90
221	0.5	90
222	2	75
223	1	90
224	1	85
225	1	90
226	3	90
227	4	140
228	2	90
229	0.5	90
230	0.5	90
231	0.5	90
232	1	90
233	1	90
234	2	90
235	1	90
236	3	90
237	0.5	90
238	1	90
239	0.5	90
240	0.5	90
241	1	90
242	1	90
243	1	90
244	1	90
245	0.5	90
246	2	90
247	3	80
248	1	90
249	0.5	90
250	0.5	90
251	1.5	90
252	0.5	90
253	1.5	90
254	13	120
255	14	105
256	8	90
257	3	90
258	1.5	90
259	1	90

260	0.5	90
261	3	90
262	19	75
263	4	85
264	1	70
265	1	90
266	4	85
267	2	90
268	11	70
269	13	75
270	5	120
271	1.5	90
272	11	90
273	0.5	90
274	1	90
275	1	90
276	10	95
277	0.5	90
278	0.4	90
279	8	90
280	1	90
281	0.5	90
282	1.5	90
283	5	50
284	10	70
285	1	90
286	8	90
287	1	90
288	3	90
289	11	90
290	1.5	90
291	14	90
292	3	90
293	2	90
294	12	90
295	9	80
296	1	90
297	0.5	90
298	1	90
299	10	90
300	6	90
301	54	65
302	13	90
303	9	90
304	3	115
305	0.5	90
306	26	75
307	30	90
308	1	90
309	6	90
310	7	90
311	2	90

312	1	90
313	51	100
314	1.5	90
315	13	95
316	1	90
317	0.5	90
318	16	125

Appendix 3: Gully Charateristics

number	branches	order	vegetation	stream	shape	length(mm)	angle	
1	0	1	1	1	1	4	90	0=yes
2	0	1	1	1	1	0.8	90	1=no
3	0	1	1	1	1	0.5	90	0=u
4	0	1	1	1	1	2	73	1=v
5	0	1	0	1	1	3.5	90	
6	0	1	0	0	0	14	123	
7	0	1	0	0	1	2	138	
8	0	1	1	0	1	0.5	90	
9	0	1	1	0	0	1.8	70	
10	0	1	0	0	1	8	135	
11	0	1	0	0	0	13	135	
12	0	1	1	1	1	0.5	90	
13	0	1	1	1	1	0.7	90	
14	0	1	1	1	1	1.5	90	
15	0	1	1	1	1	1	90	
16	0	1	1	1	1	0.5	90	
17	0	1	1	1	1	1.5	90	
18	0	1	0	1	0	6.5	80	
19	0	1	0	0	0	9	85	
20	0	1	1	1	1	1	90	
21	0	1	1	1	1	1	90	
22	2	2	0	0	0	7.5	100	
23	1	2	0	1	0	6	60	
24	0	1	1	1	1	0.4	90	
25	0	1	1	1	1	0.4	90	
26	0	1	0	0	0	12	110	
27	0	1	1	1	1	1.5	90	
28	0	1	1	1	1	0.4	90	
29	0	1	1	1	1	0.4	90	
30	0	1	0	1	0	5	90	
31	0	1	0	0	0	13	90	
32	0	1	0	0	0	7	118	
33	3	2	0	0	0	18	90	
34	0	1	0	1	0	16	120	
35	0	1	0	1	0	2	90	
36	0	1	0	0	0	5	110	
37	1	2	0	1	0	11	90	
38	0	1	0	1	0	6	90	
39	0	1	1	1	1	1	9	
40	0	1	0	0	0	3	90	
41	2	2	0	0	0	4	90	
42	0	1	0	0	0	5	70	
43	1	2	0	0	0	6	75	
44	2	2	0	0	0	9	80	
45	0	1	0	1	0	14	80	
46	3	2	0	0	0	17	90	
47	1	2	0	0	0	10	87	
48	4	3	0	0	0	14	90	
49	0	1	0	1	0	5.5	90	
50	0	1	0	1	0	2	90	

51	0	1	0	0	0	4	90
52	0	1	0	1	0	6	125
53	0	1	0	1	0	8	100
54	0	1	1	1	0	2	90
55	2	2	0	1	0	8	100
56	2	2	0	0	0	8	90
57	3	2	0	0	0	6	90
58	0	1	0	1	1	1	90
59	0	1	0	1	0	3	70
60	0	1	0	0	0	50	90
61	5	2	0	0	0	16	90
62	0	1	0	1	0	4	58
63	9	3	0	1	0	10	90
64	4	2	0	0	0	31	90
65	0	1	1	1	1	0.8	90
66	0	1	1	1	1	0.5	90
67	0	1	0	0	0	56	95
68	0	1	1	1	1	0.5	90
69	0	1	1	1	1	0.5	90
70	0	1	1	1	1	0.5	90
71	0	1	1	1	1	2.5	70
72	2	2	0	0	0	7	90
73	3	2	0	0	0	29	110
74	0	1	1	1	1	0.5	90
75	8	4	0	0	0	6	110
76	0	1	0	1	0	1	90
77	2	2	0	1	0	0.8	95
78	0	1	1	1	1	0.9	90
79	0	1	1	1	1	0.5	90
80	0	1	0	1	0	3	90
81	0	1	1	1	1	0.4	90
82	0	1	1	1	1	1	90
83	0	1	1	1	1	2	90
84	2	2	0	0	0	85	90
85	0	1	1	1	1	3	78
86	0	1	1	1	1	0.5	90
87	0	1	1	1	1	0.5	90
88	0	1	1	1	1	1.4	90
89	0	1	1	1	1	1.5	60
90	0	1	1	1	1	1.5	90
91	0	1	1	1	1	1	90
92	0	1	1	1	1	1	90
93	0	1	1	1	1	2	90
94	0	1	1	1	1	0.5	90
95	0	1	1	1	1	1.5	90
96	2	2	0	0	0	6	70
97	0	1	1	1	1	1	90
98	3	2	0	0	0	12	90
99	0	1	1	1	1	0.5	90
100	0	1	1	1	1	1	90
101	10	3	0	0	0	36	118
102	0	1	0	1	1	1	90
103	0	1	1	1	1	0.5	90
104	0	1	0	1	0	4	90
105	0	1	0	1	1	1	90

106	0	1	0	1	1	1	90
107	0	1	1	1	1	1	90
108	0	1	0	1	0	11	110
109	3	2	0	1	0	3	130
110	10	3	0	0	0	11	100
111	0	1	0	1	0	2	105
112	0	1	0	1	0	1.5	90
113	1	2	0	0	0	38	105
114	3	2	0	1	0	3	90
115	0	1	0	0	0	19	120
116	7	3	0	0	0	10	90
117	2	2	0	1	0	5	90
118	0	1	1	1	1	1	90
119	0	1	0	1	1	0.5	90
120	2	2	0	1	1	8	95
121	2	2	0	0	0	13	123
122	0	1	0	1	0	5	80
123	0	1	0	1	1	1.5	90
124	11	3	0	0	0	48	90
125	2	2	0	1	0	3	90
126	0	1	0	1	0	1	90
127	0	1	1	1	1	0.8	90
128	0	1	1	1	1	0.8	90
129	2	2	0	1	0	1.4	90
130	3	2	0	0	0	46	105
131	0	1	1	1	1	0.5	90
132	0	1	1	1	1	1	90
133	0	1	0	1	0	3	90
134	2	2	0	1	0	4	90
135	2	2	0	1	0	4	90
136	0	1	0	0	0	41	86
137	0	1	1	1	1	43	85
138	0	1	1	1	1	3	90
139	2	2	1	1	1	1.8	90
140	0	1	1	1	1	1	90
141	5	3	0	0	0	38	90
142	3	2	0	0	0	10	110
143	5	2	0	0	0	52	90
144	0	1	0	1	0	13	100
145	0	1	1	1	1	1	90
146	2	2	1	1	1	1.5	85
147	0	1	1	1	1	1	90
148	3	2	0	0	0	67	100
149	4	2	0	0	0	51	95
150	0	1	1	1	1	2	90
151	0	1	1	1	1	1.5	90
152	0	1	1	1	1	1.5	90
153	5	2	0	1	0	23	105
154	12	3	0	0	0	45	90
155	0	1	1	1	1	1	90
156	0	1	1	1	1	1	90
157	15	3	0	0	0	37	110
158	3	2	0	0	0	10	100
159	3	2	0	1	0	6	90

160	0	1	1	1	1	1	85
161	3	2	1	1	1	3	69
162	2	2	0	1	0	10	90
163	3	2	0	1	0	11	90
164	4	2	0	0	0	65	105
165	2	2	0	1	0	2	90
166	4	2	0	1	0	5	50
167	6	2	0	0	0	21	70
168	0	1	1	1	1	2	90
169	1	2	1	1	1	1	170
170	0	1	1	1	1	3	56
171	0	1	1	1	1	3	100
172	0	1	1	1	1	3	90
173	1	2	1	1	1	2	75
174	2	2	1	1	1	2	90
175	0	1	1	1	1	3	86
176	0	1	1	1	1	1	9
177	2	2	0	1	0	5	90
178	2	2	0	1	0	8	90
179	0	1	0	1	0	5	55
180	0	1	0	1	0	3	53
181	0	1	0	1	0	2	90
182	0	1	0	1	0	2	90
183	4	2	0	1	0	12	90
184	0	1	1	1	0	5	90
185	0	1	1	1	1	1.5	90
186	0	1	1	1	1	1.5	90
187	0	1	1	1	1	1	90
188	3	2	0	1	0	8	70
189	2	2	0	1	0	5	90
190	0	1	0	0	0	15	90
191	0	1	0	1	1	1	90
192	2	2	0	0	0	15	90
193	0	1	1	1	1	8	90
194	2	2	0	0	0	22	100
195	0	1	1	1	1	2	90
196	3	2	0	1	1	5	90
197	3	2	0	1	0	4	90
198	0	1	1	1	1	2	90
199	0	1	1	1	1	1	90
200	4	2	0	0	0	28	90
201	2	2	0	0	0	18	90
202	2	2	0	0	0	9	90
203	3	2	0	1	1	8	90
204	0	1	0	0	0	14	90
205	2	2	0	1	1	4	90
206	0	1	0	0	0	23	90
207	1	2	1	1	1	1	90
208	2	2	1	1	1	1.5	70
209	0	1	1	1	1	2	85
210	3	2	1	1	1	3	90
211	3	2	0	1	0	3	90
212	2	2	0	0	0	11	90
213	3	2	0	0	0	10	70

214	0	1	1	1	1	0.8	85
215	0	1	1	1	1	1	90
216	0	1	1	1	1	1.5	90
217	0	1	1	1	1	1	90
218	0	1	1	1	1	1	90
219	0	1	1	1	1	1.2	90
220	0	1	1	1	1	2	90
221	0	1	1	1	1	1	90
222	0	1	1	1	1	0.8	90
223	0	1	1	1	1	1	90
224	0	1	1	1	1	3	80
225	0	1	1	1	1	1	90
226	0	1	1	1	1	2	90
227	0	1	1	1	1	3	90
228	0	1	1	1	1	2	100
229	0	1	1	1	1	1	90
230	0	1	1	1	1	2	90
231	0	1	1	1	1	5	90
232	0	1	1	1	1	2	90
233	0	1	1	1	1	1	90
234	0	1	1	1	1	1	90
235	0	1	1	1	1	0.4	90
236	0	1	1	1	1	0.5	90
237	0	1	1	1	1	0.5	90
238	0	1	1	1	1	0.5	90
239	0	1	1	1	1	1	90
240	0	1	1	1	1	3	93
241	0	1	1	1	1	4	80
242	0	1	1	1	1	2	90
243	0	1	1	1	1	5	90
244	0	1	1	1	1	1	90
245	0	1	0	0	0	12	117
246	1	2	0	0	0	15	108
247	2	2	0	0	0	8	90
248	0	1	0	1	0	4	90
249	0	1	1	1	1	2	90
250	0	1	1	1	1	5	90
251	0	1	0	1	0	3	90
252	4	2	0	0	0	20	75
253	0	1	0	1	1	4	90
254	0	1	1	1	1	1	90
255	0	1	1	1	1	1	90
256	0	1	0	1	0	4	87
257	2	2	0	0	0	11	90
258	2	2	0	0	0	13	90
259	0	1	0	1	0	5	110
260	0	1	0	1	1	1	90
261	3	2	0	0	0	10	90
262	0	1	1	1	1	1	70
263	0	1	1	1	1	0.5	90
264	0	1	1	1	1	1	70
265	0	1	1	1	1	1	90
266	0	1	1	1	1	1	100

267	0	1	0	1	1	2	90
268	0	1	0	1	0	3	60
269	0	1	0	0	0	10	75
270	3	2	0	0	0	9	90
271	0	1	0	1	0	3	90
272	2	2	0	0	0	12	90
273	0	1	1	1	0	1	90
274	4	2	0	0	0	14	110
275	0	1	0	1	1	3	90
276	0	1	1	1	1	2	90
277	4	3	0	0	0	13	90
278	2	2	0	1	0	10	90
279	0	1	1	1	1	1.5	90
280	0	1	1	1	1	1.5	90
281	0	1	0	1	0	10	90
282	0	1	0	1	0	5	90
283	8	3	0	0	0	54	65
284	0	1	0	0	0	10	90
285	0	1	0	1	0	3	90
286	0	1	1	1	1	0.5	90
287	2	2	0	0	0	26	75
288	5	3	0	0	0	32	110
289	0	1	0	1	1	1	90
290	0	1	0	0	0	6	90
291	2	2	0	0	0	6	67
292	0	1	0	1	0	2	90
293	0	1	1	1	1	1	90
294	7	3	0	0	0	54	90
295	0	1	1	1	1	2	90
296	0	1	0	0	0	13	90
297	0	1	1	1	1	2	90
298	0	1	0	0	0	15	120

Backispiece: How hard it is to get good help these days.
Don't they realise the study area is *behind* them.